AlphaTRAC
Meeting the Challenge of the Atmosphere

September 20, 2001

Dear Stakeholder:

The Rocky Flats Cleanup Agreement (RFCA) Stakeholder Focus Group will meet at the Broomfield Municipal Center at One DesCombes Drive on October 3, 2001 from 3:30 to 6:30 p.m. We're working on a revised agenda for the meeting which will combine the agenda originally planned for September 19, 2001 with expected advances in the RSAL project. We'll send out the new agenda to you early next week.

The presentations from the September 5, 2001 RFCA Focus Group meeting are enclosed as Attachment A, including:

- Americium Ingrowth into Generic Weapons-Grade Pu chart,
- *Precepitiation Scvenging and Atmosphere-Surface Exchange, Volume 3-The Summers Volume: Applications and Appraisals*, S.E. Schwartz, S.G.N. Slinn,
- *Measurement of resuspended aerosol in the Chernobyul area, Part III: Size distribution and dry deposition velocity of radioactgive particles during antropogenic enhanced resuspension*, E. K. Garger, H. G. Paretzke, J. Tschiersch, and
- References for the MRI Portable Wind Tunnel Method.

The August 8, 2001 RFCA Focus Group meeting minutes are enclosed (Attachment B).

During the September 5, 2001 RFCA Focus Group, members asked for the computer modeling workshop notes. Those are enclosed as Attachment C.

The RSALs Working Group met September 13, 2001. The action items and notes resulting from the meeting are enclosed as Attachment D.

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ADMIN RECORD

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DOCUMENT CLASSIFICATION REVIEW WAIVER PER CLASSIFICATION OFFICE

SW-A-004397

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Attachment E is the latest version of the preliminary surface RSAL matrix, which includes Risk calculations for the Open Space and Office Worker scenarios.

If you need additional information to prepare you for the Focus Group discussion on October 3, 2001, please contact Christine Bennett of AlphaTRAC, Inc. at 303 428-5670 (cbennett @alphatrac.com). Christine will help to find the appropriate resource for you.

You may call either Christine or me if you have any questions, comments, or suggestions concerning the RFCA Stakeholder Focus Group or the upcoming meeting.

Sincerely,

C. Reed Hodgin / cb

C. Reed Hodgin, CCM
Facilitator / Process Manager

RFCA Stakeholder Focus Group
Attachment A

Title: Presentations from the September 5, 2001 RFCA Focus Group meeting, including:

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- References for the MRI Portable Wind Tunnel Method.

Date: September 19, 2001

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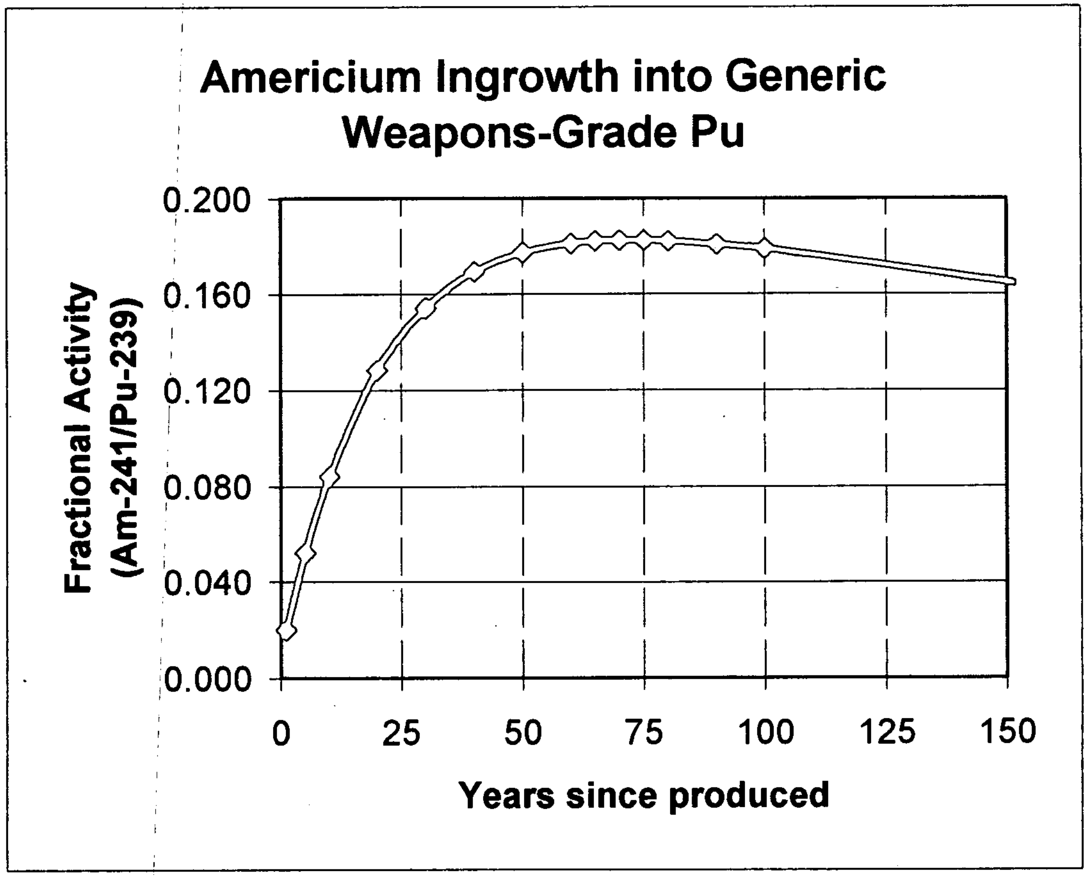

Isotope	half-life
Pu-239	24,100 yr
Pu-241	14.4 yr
Am-241	432.7 yr

Ingrowth Decay Chain

Pu-241

$\downarrow \beta^{-}$

Am-241

$\downarrow \alpha^{2+}$

Np-238

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PRECIPITATION SCAVENGING AND ATMOSPHERE-SURFACE EXCHANGE

Volume 3—The Summers Volume: Applications and Appraisals

Coordinated by

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Enhancement Factors for Resuspended Aerosol Radioactivity: Effects of Topsoil Disturbance

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ABSTRACT

The enhancement factor for airborne radionuclides resuspended by wind is defined as the ratio of the activity density (Bq g^{-1}) in the aerosol to the activity density in the underlying surface of contaminated soil. Enhancement factors are useful for assessment of worst-case exposure scenarios and transport conditions, and are one of the criteria for setting environmental standards for radioactivity in soil. This paper presents results of experimental studies where resuspension of ^{239}Pu was measured when air concentrations were equilibrated to the soil surface. Enhancement factors were observed for several types of man-made disturbances (bulldozer-blading, soil raking, vacuum-cleaning) and natural disturbances (springtime thaw, soil-drying, wildfire). For some cases, enhancement factors are compared over a range of geographical locations (Bikini Atoll, California, Nevada, and South Carolina). The particle-size distributions of aerosol activity are compared to particle-size distributions of the underlying soil.

1. INTRODUCTION

It is sometimes important to estimate the radioactivity in aerosols that have been resuspended from a contaminated soil surface. For example, it is common in environmental risk assessments to estimate an approximate or worst-case aerosol concentration, C, by multiplying an observed suspended dust particulate concentration, M (g m^{-3}), by the activity of a particular radionuclide, A (Bq g^{-1}), in the soil. This estimate may be improved with further multiplication by an enhancement factor, EF, to include disturbance effects on the soil:

$$C = EF \times M \times A \qquad (1)$$

In the case where one can be assured that the airborne concentration of radionuclides is in equilibrium with the underlying soil surface, it is possible to observe the EF directly. Strictly speaking, the EF is the ratio of the activity density of the suspended aerosols (Bq g^{-1}) to the activity density of the underlying soil, but only when the condition is met that there are no "imported" aerosols in the air sample. This problem was pointed out in data analyses by Sehmel (1983). One case when the condition is assured is the micrometeorological requirement for the uniformity of horizontal upwind fetch. That is, the extent of upwind soil-contamination level, surface roughness, and vegetation cover is uniform at a distance sufficiently far that there are no appreciable horizontal gradients and wind-erosion flux (resuspension) depends only on vertical gradients of particle concentration. Because of the depth of the surface boundary layer, which increases approximately linearly with distance from an upwind discontinuity, it is necessary to make vertical-gradient measurements within two meters above the surface to meet the horizontal upwind fetch requirements of 50 m to 100 m of uniform surface contamination. In practical terms, such uniform zones of contamination are rarely found, but they do provide unique sites of opportunity for studying resuspension and the airborne activity densities (Shinn, Homan, and Gay, 1982).

Another case when there is unlikely to be "imported" radioactivity in the airborne particle activity density is when a wind tunnel is used during measurements, and the horizontal scale is compressed over which the uniform upwind fetch requirement must be met. Bottomless, portable wind tunnels have been employed to conduct resuspension studies over natural surfaces (Garland, 1979; Shinn, Homan, and Gay, 1982). In order to use this method to get activity densities, there must be essentially no radioactivity in the background air measurements at the wind-tunnel intake, and the representative airborne-activity densities must be determined within the shallow surface boundary layer of the wind tunnel (less than the half-height of the wind tunnel at the outflow end). It has been shown (Shinn and Homan, 1987) that the vertical profiles in the wind tunnel are similar to those observed in the field over the same natural soil-surface conditions, provided a different scale factor is used for vertical similarity, for example, 9-cm depth of scale in the wind tunnel compared with 100 cm in the field for the same applied surface-shearing stress.

A third case when the effects of any "imported" airborne radioactivity might be minimal is when a regional equilibrium is obtained between the resuspended aerosols and the underlying soil surface. Such a condition is difficult to predict, and only when long-term monitoring shows that inflow and outflow concentrations are the same can it reasonably be assumed that an equilibrium activity density for a region has been observed.

In this paper are presented the results of many observations during the three cases discussed above; the activity density was determined during equilibrium conditions and, in turn, the EF was computed. Of special interest are the observations made following disturbance of the surface, so that a range of EF values was obtained. It should be pointed out that no attempt is made to adjust EF for the difference in particle size of the soil host compared to the particle size of the suspended aerosol. (In fact, we know something about these particle-size distributions which we will discuss later.) In the absence of our ability to understand and quantify the myriad factors of geology, soil structure, soil texture, soil moisture, soil cohesion, organic matter, ridge roughness, and so on, which influence the availability of soil particles to erosion by the wind, we are forced to use EF values obtained by empirical observation as a means of estimation of the possible ranges in exposure concentrations (C, in Equation 1).

2. EXPERIMENTAL METHODS

2.1 Soil Concentrations.

Soil samples were taken by the standard Nevada Applied Ecology Group method: from the surface, a 12.7-cm-diameter ring template was used to extract a core of 2.5-cm depth. Samples were oven dried, weighed, and sieved to pass a 1.7-mm opening. Soils were homogenized by mixing in a roller-mill and analyzed by either one of two methods: the Pu-daughter isotope, ^{241}Am, was determined by a Ge solid-state detector with pulse-height spectrometer to measure 60-keV gamma emissions, or both the ^{241}Am and the ^{239}Pu were determined by special alpha chemistry methods to a precision of 3 mBq. In the latter case, the ^{239}Pu values contain a negligible amount of ^{240}Pu also. The ratio of Pu/Am was obtained by alpha spectrometry in order to make field determination of approximate ^{239}Pu concentrations using *in situ* gamma spectroscopy with portable systems; these had a circular view of the surface over several meters in radius and a precision for ^{241}Am of about 20 mBq g^{-1}. The portable systems were used to map the soil contamination and to assure horizontal uniformity of the soil concentration (Shinn et al., 1989).

2.2 Aerosol Concentrations

High-volume (HV) samplers were used to obtain air samples for periods from 3 to 14 days on either glass-fiber or cellulose-fiber filters at a nominal flow rate of 100 m^3 h^{-1}. The filters were totally dissolved and analyzed to obtain both ^{239}Pu and ^{241}Am by the same special alpha chemistry as was used for the soil samples. In addition to HV, cascade impactors were used to obtain size distributions of resuspended particles and for redundancy to simultaneous HV samples. The cascade impactors were 5-stage jet-plate type with fiber filters, which practically eliminate any bounce-off problems on intermediate stages. The cascade impactors were operated at about 33 m^3 h^{-1}, and the filters were analyzed in the same way as the HV filters. HV and cascade filters were weighed on a precision balance before and after exposure after the filters were equilbrated to at a standard temperature and low humidity. The HV and cascade impactor measurements were made in standard HV enclosures at the 1.2-m height and were located at sites that met the requirements discussed in the Introduction.

3. RESULTS

3.1 Regional and Seasonal Effects

The seasonal trend of particulate concentration (M, in Equation 1), the specific activity of ^{239}Pu in air, and the air concentration of ^{239}Pu (C, in Equation 1), were monitored for one year in Area 5 at the Nevada Test Site, beginning in February of 1981. Two stations were located about 5 km apart along the upwind-downwind axis of the prevalent wind in Frenchman Basin: the upwind station was to the southwest about 200 m east of Well 5B, and the downwind station was on the northeast end of Frenchman Playa at the 62-m meteorological tower. Prevalent winds (daytime) are from the southwest every month of the year, while nighttime winds are weak, with divergent upslope flows off the Basin floor after sunrise and convergent downslope flows into the Basin beginning at sunset. The two stations were in remarkably good agreement for values of measured quantities averaged over two-week periods, which gives assurance that they were equilibrium values representative of the region. The important observation was that the values of M and activity were seasonally out of phase. The dust concentration, M, reached a peak in the mid-summer dry period as one might expect, but the ^{239}Pu activity density reached a peak in the springtime with the increasing values correlated to increasing numbers of frost-free days in springtime (days with observed minimum air temperature above freezing). The data are shown on Figure 1 and a smooth curve has been fitted by Hanning smoothing. The spring-thaw effect produced an increase in the air activity density by a factor of about 6.5, and assuming that the soil concentrations of ^{239}Pu radioactivity were constant, we would estimate that the EF, which is normally near unity, was increased to a value of 6.5 by the spring thaw.

3.2 Enhancement Factors in Non-Disturbed Cases

The EF values were determined for desert-pavement covered soils at Nevada Test Site and for stabilized, cultivated fields at Bikini Island, South Carolina, and California. The values for those sites were typically unity or slightly less. At the Nevada Test Site, experiments were conducted in the 1960's in which ^{239}Pu was deposited on the soil by non-nuclear explosions. Measurements of EF at Area 5, GMX, gave a mean value of 0.87 and at Area 11, Site D, gave a mean value of 1.04. These

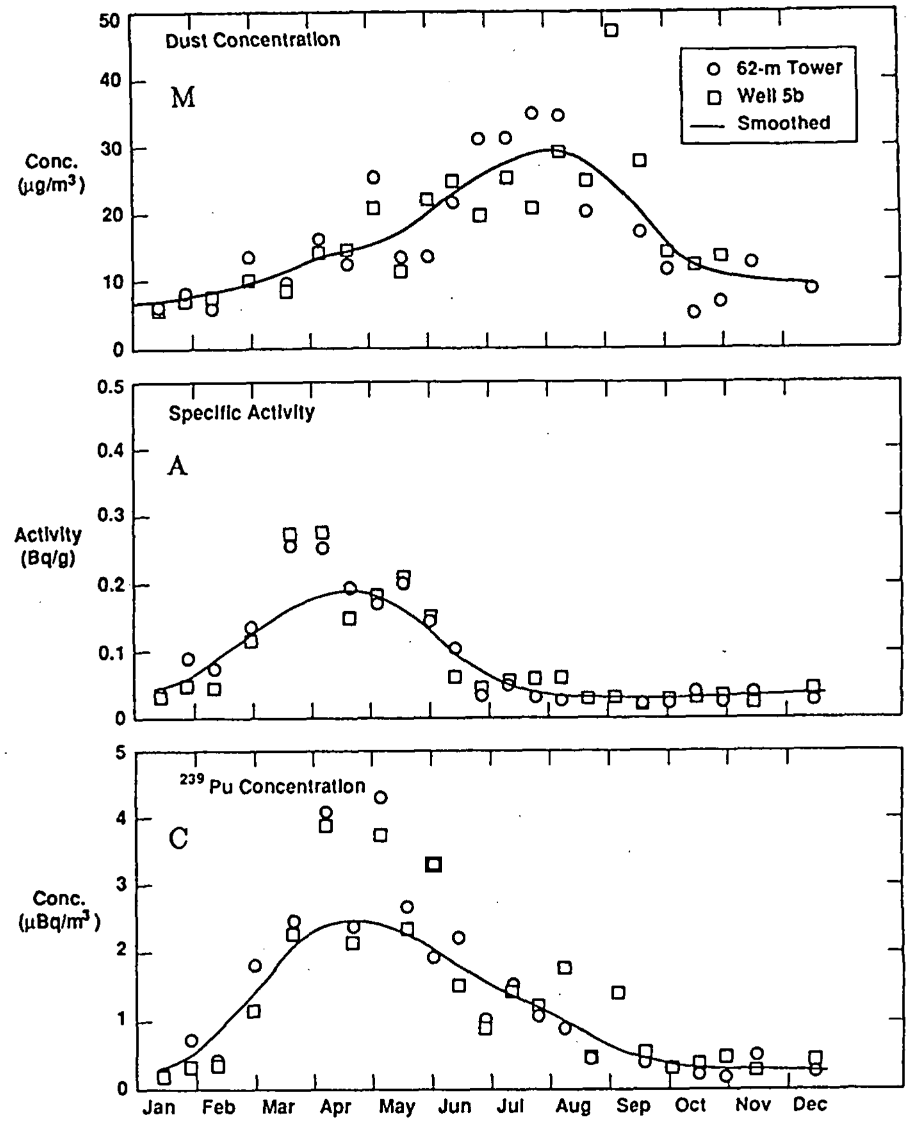

FIGURE 1. Seasonal course of M, A, and C during 1981 in Area 5 of the Nevada Test Site. (Here A is the activity in the air.)

values should be compared with EF values close to nuclear event sites at the Nevada Test Site, where the ^{239}Pu is contained in small glass beads mixed into the soil and the EF values are two to three orders of magnitude less than unity and less of an inhalation exposure threat. For example, at Area 18, Little Fellow II site, the EF was 0.024 and at Area 20, Palanquin site the EF was 0.002. See Table 1.

For cultivated fields that had been cleared of vegetation, the topsoil stirred by farm implements, and the bare soil allowed to settle for one week, the EF values were all less than unity. At Bikini Island, which had been contaminated by fallout ^{239}Pu at some distance upwind, the EF under these conditions was 0.80. At Savannah River Laboratory, South Carolina, two fields that had been contaminated by ^{239}Pu from a nearby smokestack had EF values of 0.21 and 0.49. For a small garden plot at Lawrence Livermore National Laboratory that had been contaminated by ^{239}Pu in sewage sludge, the wind tunnel was used to obtain an EF value of 0.73. The EF values for cultivated fields are compared to other cases, such as at the Nevada Test Site, in Table 1.

TABLE 1. Typical Enhancement Factors for ^{239}Pu in Aerosols Resuspended from Soils at Nevada Test Site and from Bare Fields.

	Site	EF	Contaminating Event
1.	Nevada Test Site*		
	Area 5, Site D	0.87	Safety shot.
	Area 11, Site D	1.04	Safety shot.
	Area 18, Little Fellow II	0.024	Nuclear shot.
	Area 20, Palanquin	0.002	Nuclear shot.
2.	Bare Cultivated Fields		
	Bikini	0.80	Nuclear fallout.
	South Carolina, Field 1	0.21	Processing facility.
	South Carolina, Field 2	0.49	Processing facility.
	California	0.73	Sewage sludge.

*NTS locations have desert pavement and 5-20% native plant cover.

3.3 Enhancement Factors in Disturbed Cases

Several conditions of disturbance to the topsoil yielded empirical observations of effects on EF values. In no case was the disturbance so great as to effect more than an order of magnitude increase in EF, this usually occurred after drastic stirring of the surface, e.g., bulldozing, tilling, raking-off of desert pavement. At Bikini Island, the first few days after bulldozing and clearing the vegetation from a field, the EF value was increased by a factor of 3.9. At the Nevada Test Site, Area 11, a cleanup that involved tilling and removal of 60% of the surface soil by a single pass of a vacuum cleaner resulted in an increase in EF by a factor of 3.6. At the Nevada Test Site, Area 20, the effect of a natural wildfire that removed all the grass cover was to increase the EF by a factor of 3.5. In the case of studies to evaluate the efficiency of desert pavements, the increased wind erosion caused by hand-raking to remove the pebble cover resulted in an increase in EF by a factor of 2.2. And, when the soil surface on a field in South Carolina dried out after a soaking rain, the EF remained about the same. The factors of increase of EF are compared in Table 2 as well as the factor caused by springtime thaw. It should be emphasized that the values given in Table 2 were not the EF values but the factors of increase of EF values, so that only when the undisturbed EF was unity would the disturbance EF have the values given in Table 2.

It is interesting to contemplate how difficult it is on the basis of first principles to predict what might have happened during these disturbances. Most of the physical constants of the soil must have stayed the same (bulk density, surface roughness, soil texture, and even soil moisture), but there were more contaminant particles available for wind erosion nevertheless. In these cases, empirical observations may have to suffice for environmental risk assessments.

TABLE 2. Observed Factors of Increase in Aerosol Activity of $^{239}Pu(Bq/g)$ due to Soil Disturbance.

Type of Disturbance	Relative Increase	Site
Soil thawing in springtime.	6.5	NTS, Area 05
Bulldozer blading.	3.9	Bikini
After 60% vacuum cleanup.	3.6	NTS, Area 11
Wildfire, removing grasses.	3.5	NTS, Area 20
Raked off desert pavement.	2.2	NTS, Area 18
Soil dried and eroded for 2 weeks.	0.8	So. Carolina

3.4 Changes in the Airborne Particle Size Distributions

During many of the experimental determinations of air-activity density, the particle-size distributions were measured for aerodynamic diameters between 0.3 and 10 μm. These data show almost universally that the ^{239}Pu activity density was approximately log-normally distributed across particle diameters and have median aerodynamic diameters in the range of 2 to 6 μm. The geometric standard deviations of airborne activity density had a range between 2 and 3.6 (nondimensional units), while quite often the suspended soil dust had a much broader distribution with geometric standard deviations in excess of 6. This points out that the resuspended ^{239}Pu was bound to a particularly narrow range of the soil particles available for wind erosion. In all of the cases observed, however, disturbance had a minor effect on the particle-size distributions. Only a slight decrease in the median aerodynamic diameter was noted, and that may not have been statistically significant. It remains to be shown that particles are freed by the disturbances.

Lee, Tamura, and Essington (1987) have found that soils at Nevada Test Site that have been contaminated by ^{239}Pu, have only 1% of the total ^{239}Pu associated with soil particles below 5 μm in diameter. Yet that was the particle size which was active in resuspension, and which was in the respirable size range. It may be only coincidence that the undisturbed EF values tend to unity, because that practically negligible fraction of the soil accounts for all of the resuspension and the amplification of that fraction must therefore be enormous.

4. CONCLUSIONS

The complexities of all the geophysical processes affecting the wind-erosion process make it necessary to rely on the empirical estimation of the activity density of resuspended radioactivity. To this end, the observed EF values serve the useful purpose of allowing an estimate of air exposures for an unusual range of natural and disturbed soil conditions. For the purposes of most environmental risk assessments, the EF values should be entirely satisfactory considering the possible alternatives of unviable theoretical prediction and of site-specific monitoring.

5. REFERENCES

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Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract #W-7405-ENG-48.

DISCUSSION

J. A. GARLAND. The results presented here suggest that the EF approach can be applied with uncertainties that are probably smaller than those in other approaches. It necessitates the measurement of airborne mass concentration, and the value of the method may depend on whether the mass concentration varies very much with surface condition, so I would like to ask the author whether the disturbances to the surface resulted in much change in airborne mass concentration.

J. H. SHINN. We have observed increases in airborne mass concentrations in the respirable size range in every case when the surface of the soil was disturbed. The degree of this effect of course is unpredictable and must be determined empirically, but the increase in EF is independent of that effect. We are not suggesting that airborne concentration should be estimated by EF alone, without the accompanying measurement of airborne mass.

J. A. GARLAND. Like the resuspension factor method, this approach may be of limited value in areas of inhomogeneous contamination. Has the author any experience of the problems that arise in these circumstances?

J. H. SHINN. A major point of this paper is that you have to go to great pains to determine the airborne activity density and the EF when the conditions of horizontal homogeneity are met. Having so determined the EF, however, doesn't mean that it shouldn't apply more than locally. That is, if the meteorological conditions (surface roughness, etc) remain horizontally uniform, and the soil surface properties except for contamination level remain uniform, then the EF and also the resuspension factor could be applied with the aid of a diffusion model to estimate downwind concentrations over a large area.

R. JAENICKE. You claim that the greatest mass of soil is in particles larger than 5 micrometers. For resuspension calculations it is probably appropriate to restrict the observation to those soil particles which might be transported over large distances. Such a limit would be in the 3-5 micrometer range.

J. H. SHINN. The observation of aerosol particles is restricted to the size range less that about 10 micrometers by virtue of the types of filter-impactors, optical particle counters, and other methods we use. And of course, these are the particles which are transported long-range and have a small settling velocity compared to the turbulent transport velocities. But it is useful nevertheless to examine how the radioactivity is distributed in the soil. Having said that I must point out that the latter is seldom done because it is very difficult to determine the distribution in the soil with any detail below the particle size of 5 micrometers.

R. JAENICKE. Your wind tunnel is open at the bottom. Does the wind tunnel not produce a very special climate?

J. H. SHINN. The wind tunnel is sealed to the soil on the sides, and is intended only to produce a steady surface shearing stress on the soil. It is made portable so that it does not need to stay too long in one place, and the soil and ground cover conditions could be quite natural. There may be other limitations of the tunnel, but it is a very useful tool in a supplementary sense.

S. E. SCHWARTZ. You discussed airborne particle size distributions for radioactivity and dust that were lognormal. Are these data or schematic?

J. H. SHINN. We have lots of data on airborne particle size over the range from 0.3 to 10 micrometers from both cascade impactors and optical particle counters. At these remote sites the distributions are approximately lognormal with the medians and geometric standard deviations I presented. Strictly speaking, however, the lognormal approximation applies only to that range investigated.

O. I. VOZZHENNIKOV. It seems important to emphasize the advantages of EF to the commonly used resuspension factor.

J. H. SHINN. The EF offers more information about the surface condition than the resuspension factor in the case of an aged deposit. But it is empirical nevertheless, and we admit that the soil processes are too complex to quantify when we resort to such an approach. We use the EF when seeking to put bounds on the air concentration estimates, for example.

O. I. VOZZHENNIKOV. The soil activity, A, in your tests depends on particles on the surface which resuspend. The conditions on the surface can be different from those at a certain depth. Is this limitation of the method inherent in undisturbed soil?

J. H. SHINN. It is commonly known that there is an approximate exponential decrease of activity with depth between 2 and 10 cm in the soil. On the other hand, this function probably does not apply above 2 cm. We believe that the soil surface is well-mixed in the first few centimeters, because the geophysical and biological factors are very active in the span of a few years. For example, rain drop impact, shrinking-swelling cycles, wind saltation, root growth, freezing-thawing, etc, are processes which mix the surface. Our studies show also that the statistical variability of surface soil samples is quite large even when normalized to the total deposition. This means that the problem is difficult to study but perhaps more studies are needed.

O. I. VOZZHENNIKOV. In this respect it would be interesting to discuss a hypothesis of a thin sublayer (less than the roughness length) in which concentration of radioactive dust is in equilibrium with pollution density of the soil surface. What is your view of the problem.

J. H. SHINN. In principle, I agree that this hypothesis has merit. But there are a few factors which make the hypothesis difficult to test except for some very ideal cases. First, all natural surfaces of interest have a zero-plane displacement of the atmospheric surface boundary layer. Even in bare soil, the ridge roughness is as large as the aerodynamic surface roughness length. Perhaps this is the layer which is in equilibrium. Second, I cannot think of a method to test the hypothesis that is experimentally nonintrusive. Our methods of particle collection are bulky and flow distorting when placed so near the ground. So I remain interested in the hypothesis, but I haven't resolved the question of how to test it.

Radiat Environ Biophys (1998) 37: 201–208

ORIGINAL PAPER

E. K. Garger · H. G. Paretzke · J. Tschiersch

Measurement of resuspended aerosol in the Chernobyl area

Part III. Size distribution and dry deposition velocity of radioactive particles during anthropogenic enhanced resuspension

Received: 17 February 1998 / Accepted in revised form: 17 June 1998

Abstract During anthropogenic activities, such as agricultural soil management and traffic on unpaved roads, size distribution measurements were performed of atmospheric particulate radionuclides at a site in the Chernobyl 30-km exclusion zone. Analysis of cascade impactor measurements showed an increase of the total atmospheric radioactivity. In the cases of harrowing by a tractor and traffic on unpaved roads, a common shape of the size distribution was found with two maxima, the first in the 2–4 μm range, the second in the 12–20 μm range. The size distributions were compared to measurements during wind-driven resuspension. Particle number concentration measurements with an Aerodynamic Particle Sizer showed a dynamic dependence of the particle concentration in different size ranges on anthropogenic action. The increase of the mean concentration was for the large particles more than one order of magnitude higher than for fine particles during anthropogenic enhanced resuspension. From the measurement of the mass concentration, the radioactive loading could be estimated. An enrichment of radionuclides on resuspended particles (compared to soil particles) was found, with the highest enrichment for large particles. Micrometeorological considerations showed that large particles may frequently be subject to medium range transport. The dry deposition velocity was measured; the mean value of $0.026\ m\ s^{-1} \pm 0.016\ m\ s^{-1}$ is typical for 6–9 μm diameter particles.

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Introduction

Anthropogenic activities, such as agricultural soil management (e.g. harrowing, ploughing) or automobile traffic (especially on unpaved roads), can significantly enhance the atmospheric soil dust concentration. Radionuclides which are already deposited will be resuspended together with the soil dust. The enhanced resuspension of radionuclides will affect the inhalation dose and the spread of contamination, at least on a local scale. In particular, concern is warranted for persons who are involved in the activities or live downwind close to roads and agriculturally used land.

To investigate the influence of different types of anthropogenic activities on the resuspension process and on the secondary contamination, measurements were performed in the 30-km exclusion zone of the Chernobyl Nuclear Power Plant (NPP). The study was part of two scientific programmes, one initiated by the European Parliament ("Contamination of surfaces by resuspended material", ECP1) and the other launched by the Hydrometeorological Committee of the USSR. In a series of publications, results are presented of the programmes about resuspended radioactive aerosol in the Chernobyl area. In the first paper, the instrumentation and the measurement uncertainties were discussed [1]. In the second paper, an analysis was presented of size distributions of radionuclides in air resuspended by wind, as measured since 1986 [2]. In this last publication of the series, the results are presented of measurements performed in 1993 during enhanced resuspension due to various anthropogenic activities.

Emphasis in the present work is on describing the resuspended radioactive particles in terms of number and size with regard to spread of contamination and estimation of inhalation dose. The experimental information on the particle size distribution can be used directly, avoiding any general assumptions. Moreover, the proportions of the fine and coarse particles can be estimated for the processes of transport and redistribution of contamination. For different anthropogenic activities, this may result in different effective scales for potential effects. The redistribution esti-

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mation requires knowledge of the resuspension and the deposition rate. Therefore, the dry deposition velocity was determined experimentally as well.

Materials and methods

The resuspension measurements were carried out at the permanent field site Zapolie, a location inside the 30-km exclusion zone approximately 14 km south of Chernobyl NPP. The site Zapolie is located on a large open grass field with an area of approximately 1800 m by 600 m, where since July 1986 many investigations have taken place [3]. Anthropogenic enhanced resuspension was measured during different simulated agricultural activities and operations of different trucks. Two different soil surfaces free of vegetation were prepared on which several tractor types were driven, simulating soil management such as harrowing. The soil surface strips represent fixed line sources. In a typical experiment, the tractor started at one end of the strip, passed the sampler at a certain fixed distance, drove to the other end of the prepared surface and returned. For a certain experiment, the strip was chosen for which the wind trajectories pass the sampling equipment after crossing the prepared surface. Detailed information about the orientation of the strip sources and the positions of the different samplers are given in [4].

The size distribution of radioactive particles was measured by a cascade impactor PK [1]. The mass concentration for the different particle size ranges was determined with a Berner impactor [5]. The number concentration of airborne particles in the size range 0.6–30 µm was measured in a size-resolved manner by an Aerodynamic Particle Sizer (APS) [6]. The samplers operated close together at a sampling height of 3.0–3.5 m and at approximately 45 m from the northeastern dust strip and approximately 120 m from the southwestern strip. The vertical profile of atmospheric nuclide concentrations was determined by the installation "Grad", four identical filter samplers operating at heights 1.0, 1.8, 2.5 and 3.5 m [1]. In addition to air samples, deposited material was collected. The samples were collected on "planchettes", which are gauze-covered flat plates. The "planchettes" were placed near each other at heights 0.5, 1.0, 1.5 and 2.0 m.

At different parts of the soil strips, the ^{137}Cs inventory of the upper 5 cm soil layer was determined. For the northeast strip the mean ^{137}Cs contamination and specific activity was 0.31 MBq m^{-2}±0.05 MBq m^{-2} and 4.94 Bq g^{-1}±0.75 Bq g^{-1}, respectively (the density of the poured soil was assumed to be 1.3 g cm^{-3}); for the southwest strip they were 0.56 MBq m^{-2}±0.06 MBq m^{-2} and 8.85 Bq g^{-1}±0.98 Bq g^{-1}, respectively. The number of hot particles per unit area was 27×10^4 m^{-2} (4.2 particles g^{-1}) for the northeast strip and 60.5×10^4 m^{-2} (9.4 particles g^{-1}) for the southwest strip.

In May 1993 15 experiments were performed during anthropogenic enhanced resuspension (see Table 1). The first experiment was made during the assembling of equipment of other teams of the project: dust was raised by scientists and technicians walking near the samplers. Cutting the dry grass of the previous year around the site by a small tractor produced dust as well. Distances varied between 50 and 250 m from the central point of the site. On the following days soil management with two types of tractors (a small MTZ-82 and a big T-150) was simulated in 8 experiments. Two different trucks (a six-wheeled army truck ZIL-131 and a large truck ZIL-130) were driven on the prepared surface strips, simulating traffic on unpaved roads.

During the experiments, soil and meteorological parameters were measured as part of the project ECP1 [4]. Meteorological information was available from the Chernobyl meteorological station as well. The vertical profiles of air temperature and wind velocity were determined for micrometeorological data. The Monin-Obukhov similarity theory of the surface layer of the atmosphere [7] was used for estimation of the friction velocity and classification of the thermal stability [8].

Three of the experiments were performed during neutral thermal conditions (see Table 1): on 12 May 1993 in the afternoon and on 13 May 1993, when the Monin-Obuchov scale lengths L were approximately −100 m or less and the standard deviations of the wind direction were between 3° and 12° (at mean wind velocities from 5.0 to 6.8 m s^{-1}). In general, the experiments were performed during slightly and moderately unstable thermal conditions (-84 m $\leq L \leq -28$ m) with standard deviations of the wind direction of between 9° and 25° at wind velocities from 3.1 to 4.6 m s^{-1}. The mean roughness length was 8–10 cm during all experiments. The soil humidity decreased with time during the experimental period, thus influencing the concentration of resuspended particle mass and activity (Table 1).

Results and discussion

Results of the project measurements show that the total airborne radionuclide concentrations and deposition rates were increased considerably during anthropogenic enhanced resuspension. Depending on the experimental conditions, this increase involved a factor of several thousand in comparison with the concentrations occurring during wind resuspension at distances about 20–30 m from the dust sources and a factor 10–100 at distances of about 100 m or more [4]. The measurements of the number concentrations of hot particles show an increase of 3 orders of magnitude, reaching 0.7–1.0 hot particles/m^3 with a maximum activity of 1.5–2.0 Bq/particle.

Size distribution of radioactive particles

The arithmetic mean and the median diameter of the size distribution of the ^{137}Cs activity in air as measured by the PK impactor during the experimental period in May 1993 are given in Table 1. If we do not consider the results during assembling of the equipment and wind resuspension, the mean and median diameters of the ^{137}Cs size distributions were very similar in the experiments. The values for the 10 experiments were 7.1 µm±1.1 µm for the mean diameter and 4.4 µm±1.5 µm for the median diameter. During assembling of equipment with dust resuspension caused by people walking close to the samplers, a mean diameter of 13.8 µm and a median diameter of 11.0 µm were observed. In the experiment with only wind resuspension from the bare soil of the prepared dust strip, the mean diameter was 5.6 µm and the median, 3.0 µm.

Certain typical shapes of the measured size distributions can be distinguished. In Fig. 1 the ^{137}Cs size distributions are given in the normalized coordinates $\frac{\Delta A}{A \cdot \log d}$ and log d, where A is the air concentration of ^{137}Cs and d is the aerodynamic particle diameter. In the experiments with the tractors simulating harrowing and the trucks simulating traffic on unpaved road, very similar distributions were observed. The two maxima, the first in the range 2–4 µm (which is only weakly developed) and the second in the range 12–20 µm (which is more pronounced) are characteristic. A considerable part of the activity was measured in the fine particle range (0.1–2.0 µm): 33%±6% of the total activity. These size distributions are very similar to a

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Table 1 Experimental conditions at Zapolie in May 1993, total ^{137}Cs activity concentrations in resuspended aerosol, and parameters of ^{137}Cs activity size distributions as measured with the PK impactor

Date and time	Kind of activity	Mean wind and friction velocity (m s^{-1})	Monin-Obuchov length L (m)	Soil humidity H (%)	^{137}Cs activity concentration (mBq m^{-3})	Mean diameter (μm)	Median diameter (μm)
07.05.93–08.05.93 10^{00}–15^{20}	Assembling of equipment	4.3, 0.40	–	–	0.81	13.8	11.0
08.05.93 10^{00}–17^{00}	Grass cutting	5.6, 0.55	–	6.2	1.7	5.5	0.83
11.05.93 12^{20}–14^{10}	Harrowing small tractor	3.5, 0.31	–43	6.1	4.6	7.7	4.8
16^{15}–17^{25}		3.5, 0.32	–63	7.4			
12.05.93 11^{45}–13^{45}	Harrowing small tractor	4.6, 0.42	–38	5.2	6.7	5.6	2.6
16^{30}–18^{30}		5.0, 0.44	–96	4.9			
13.05.93 11^{30}–16^{30}	Harrowing big tractor	6.7, 0.60	–92	–	68.1	6.8	3.3
17^{15}–18^{40}		6.8, 0.61	–700	3.7			
14.05.93–20.05.93 12^{00}–10^{00}	Wind resuspension	2.2, 0.20	± ∞	5.7 7.0 7.1	0.54	5.6	3.0
21.05.93 15^{00}–16^{40}	Driving of truck ZIL131	3.1, 0.30	–42	4.0	39.3	8.1	5.3
22.05.93 10^{50}–12^{15}	Driving of truck ZIL131	4.6, 0.45	–48	2.6	78.1	8.2	6.4
15^{06}–16^{06}		4.8, 0.46	–71	2.1			
23.05.93 10^{40}–12^{50}	Harrowing small tractor	4.7, 0.47	–36	1.9	41.7	7.1	5.0
24.05.93 15^{30}–18^{30}	Driving of the trucks ZIL130 and ZIL131	3.1, 0.31	–28	1.4	96.7	6.6	3.6
25.05.93 11^{15}–13^{05}	Harrowing small tractor	5.0, 0.48	–56	3.5	28.1	8.7	6.8
25.05.93 16^{00}–17^{10}	Driving of truck ZIL131	4.7, 0.42	–84	3.5	169	6.5	3.0

certain type of distribution measured at Zapolie under wind-driven conditions [2]. We may now explain these distributions in wind-driven conditions by the large-scale anthropogenic decontamination works close to the Chernobyl NPP at a distance of approximately 12–14 km from the sampling site.

Very different shapes of ^{137}Cs activity size distributions were measured during the other experiments. Wind resuspension across the bare soil of the prepared dust strip resulted in an unimodal distribution with the maximum in the size fraction 4–7 μm. During the assembling of equipment, a bimodal distribution was measured, with a very high maximum in the range 20–30 μm and a secondary maximum in the range 4–7 μm. Grass cutting around the site produced a very high proportion of fine particles (0.1–2 μm), but a second maximum as well in the range 20–30 μm. Comparison of these distributions again with the wind-driven cases [2] shows a striking similarity between the "assembling of equipment" distribution and the distribution type measured most frequently at Zapolie during wind resuspension. Local small-scale anthropogenic activities seem to influence the particle size distribution significantly.

The total concentrations of the radionuclides ^{238}Pu, $^{239+240}Pu$, ^{241}Am and ^{90}Sr in aerosol particles were determined by filter sampling (with the Grad sampler) and radiochemical analysis. The activity of these nuclides was compared with the total activity of ^{137}Cs, which was measured by gamma-spectrometry of the same filters. The vertical profile of the nuclide concentrations is given in Fig. 2. For the sampling height of 3.5 m (which is also the inlet height of the PK impactor), the mean ratios of the nuclides to ^{137}Cs were calculated to be 0.0103 for $^{239+240}Pu$, 0.00456 for ^{241}Am and 0.352 for ^{90}Sr. Assuming that the activity ratios did not change over different particle size ranges, an estimation was made of the distribution of these radionuclides in various size fractions according to the measured ^{137}Cs size distribution. In Table 2 the measured ^{137}Cs activity and the estimated activities of the other nuclides in the different size ranges are given for two experiments with heavy anthropogenic activities. The air concentrations of the plutonium nuclides were significant with

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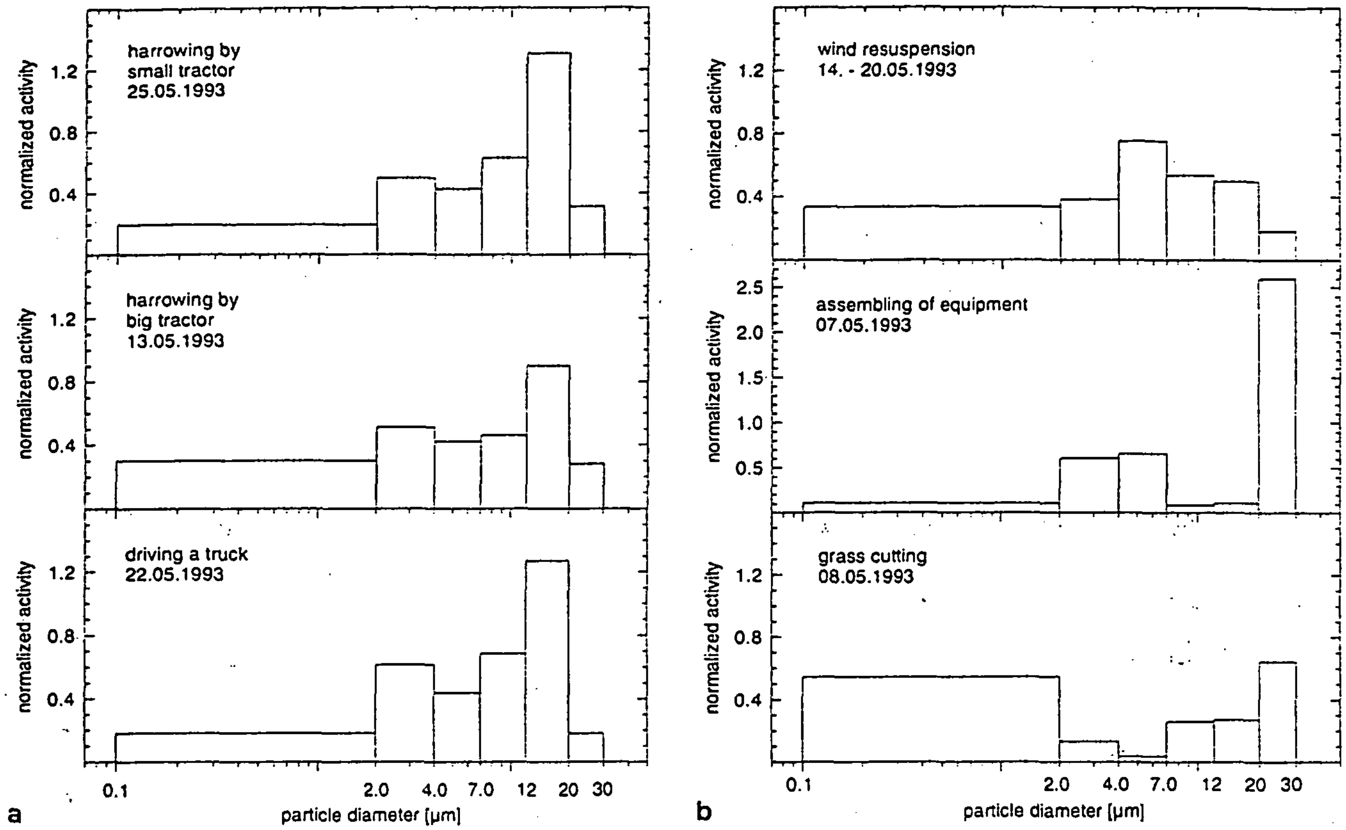

Fig. 1a, b ^{137}Cs activity size distributions in the normalized coordinates $\frac{\Delta A}{A \cdot \Delta \log d}$ and log d, where A is the air concentration of ^{137}Cs and d is the aerodynamic particle diameter, during resuspension experiments in May 1993 at Zapolie. The first three distributions are typical for simulated soil management and traffic on unpaved roads. The other distributions are results of single experiments

regard to inhalation dose and spread of contamination for the fine particle range (0.1–2.0 μm), with 36%–40% of the total concentration, and the giant particle range (12.0–20.0 μm), with approximately 20% of the total concentration.

The transport behaviour of particles in the surface layer of the atmosphere depends on the ratio of the settling velocity of aerosol particles and the friction velocity [8, 9]. To assess the relevance of particles in the different particle size ranges for medium range transport and inhalation, the settling velocity w_g of aerosol particles was compared to the atmospheric friction velocity u_*. For fine particles with their very small settling velocities, it is well-known that they can be transported long distances from fields undergoing agricultural activities. At a soil density of ρ=2.3 g cm^{-3}, the settling velocity in the particle size range 12–20 μm is of the order of 1.1–3.0 cm s^{-1}. The friction velocity during the experiments was u_*=43 cm s^{-1}±0.11 cm s^{-1}, and the resulting ratio w_g/u_* was in the range 0.026–0.070. This means that particles with $d \leq 20$ μm may travel distances of the order of 1–10 km during these atmospheric stability conditions, which last typically 6–8 h

Table 2 Distribution of the activity concentrations of $^{239+240}Pu$, ^{241}Am and ^{90}Sr according to measured ^{137}Cs size distributions and the nuclide ratios of total concentration measurements at Zapolie

Date of experiment	Size range (μm)	$^{239+240}Pu$ (mBq m^{-3})	^{241}Am (mBq m^{-3})	^{90}Sr (mBq m^{-3})	^{137}Cs (mBq m^{-3})
13.05.1993	0.1–2.0	0.481	0.213	16.4	46.7
	2.0–4.0	0.184	0.0816	6.30	17.9
	4.0–7.0	0.123	0.0543	4.19	11.9
	7.0–12.0	0.129	0.0570	4.40	12.5
	12.0–20.0	0.240	0.106	8.20	23.3
	20.0–30.0	0.0591	0.0262	2.02	5.74
24.05.1993	0.1–2.0	0.355	0.157	12.1	34.5
	2.0–4.0	0.172	0.0762	5.88	16.7
	4.0–7.0	0.132	0.0584	4.51	12.8
	7.0–12.0	0.110	0.0488	3.77	10.7
	12.0–20.0	0.187	0.0830	6.41	18.2
	20.0–30.0	0.0388	0.0172	1.33	3.77

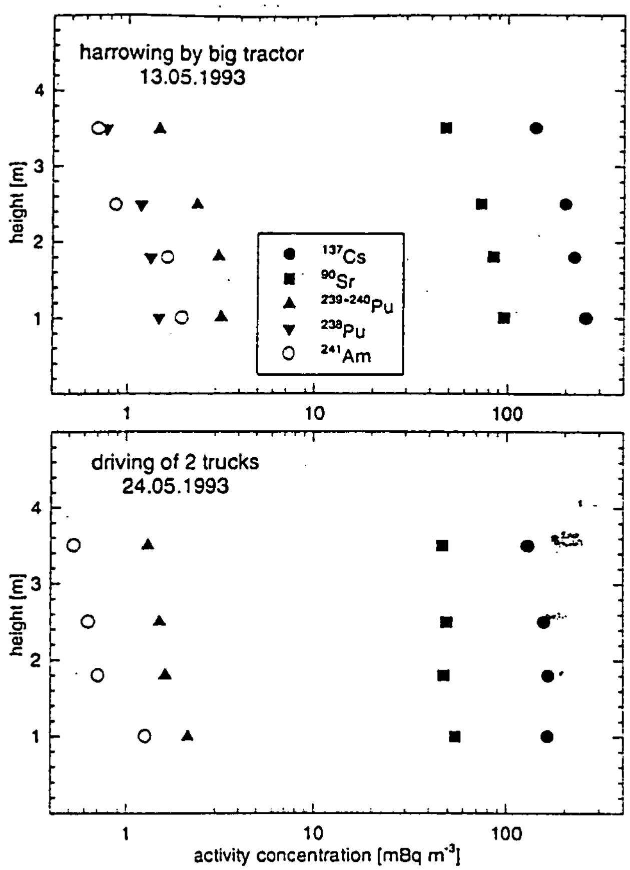

Fig. 2 Activity concentration height profile of the radionuclides ^{137}Cs, ^{238}Pu, $^{239+240}$Pu, ^{241}Am and ^{90}Sr at Zapolie during two resuspension experiments according to the filter samples of the Grad sampler

in the summer [8, 9]. Therefore, during anthropogenic enhanced resuspension, large and giant particles should be taken into consideration for inhalation dose assessment and spread of contamination as well. The possibility of atmospheric dispersion of these particles is an additional argument for the importance of taking coarse particles into account [10, Wagenpfeil et al., manuscript submitted].

The dependence of the temporal variation of airborne particle number per unit air volume on the particle size was measured by an APS. An episodic injection of a huge number of particles into the atmosphere during anthropogenic activities was observed. In Fig. 3 the temporal course of the number concentration on the afternoon of May 13th is presented after classification into four size ranges. In this example, periods of harrowing with a big tractor alternate with break periods in which there was only wind resuspension. The concentration increase in the periods of soil management is not uniform for all size ranges: the concentration of large particles increases much more than the concentration of fine particles.

In Table 3 this observation is quantified. In four size ranges parameters of the number concentration are pre-

Table 3 Parameters of number concentration measurements on 13 May 1993, afternoon, by APS during harrowing with the big tractor (N_H normalized mean concentration of particles during the harrowing periods, N_T normalized mean concentration of particles during the total experimental period, N_B normalized mean concentration of particles during break periods. S_H, S_T, S_B standard deviation of mean in the respective period. N_{max}, N_{min} maximum and minimum concentration of particles during the total experimental period)

Parameter	Particle size range			
	0.6–1.0 µm	1–3 µm	3–10 µm	10–30 µm
N_H (cm^{-3})	25.4	59.4	108.8	52.2
N_T (cm^{-3})	15.2	26.0	41.8	20.1
N_B (cm^{-3})	9.37	6.76	3.17	1.63
S_H/N_H	0.449	0.0537	0.520	0.615
S_T/N_T	0.678	1.23	1.47	1.55
S_B/N_B	0.0593	0.194	0.726	1.07
N_H/N_B	2.71	8.79	34.3	32.0
N_T/N_B	1.62	3.85	13.2	12.3
N_{max}/N_{min}	6.79	31.7	259	987

Fig. 3 Time record of the normalized particle number concentration in four different size ranges as measured by an Aerodynamic Particle Sizer during the resuspension experiment on 13 May 1993 at Zapolie. The periods of operation of the big tractor can be identified by the periods of increased particle concentrations. The increase of large particles is much larger than the increase of fine particles

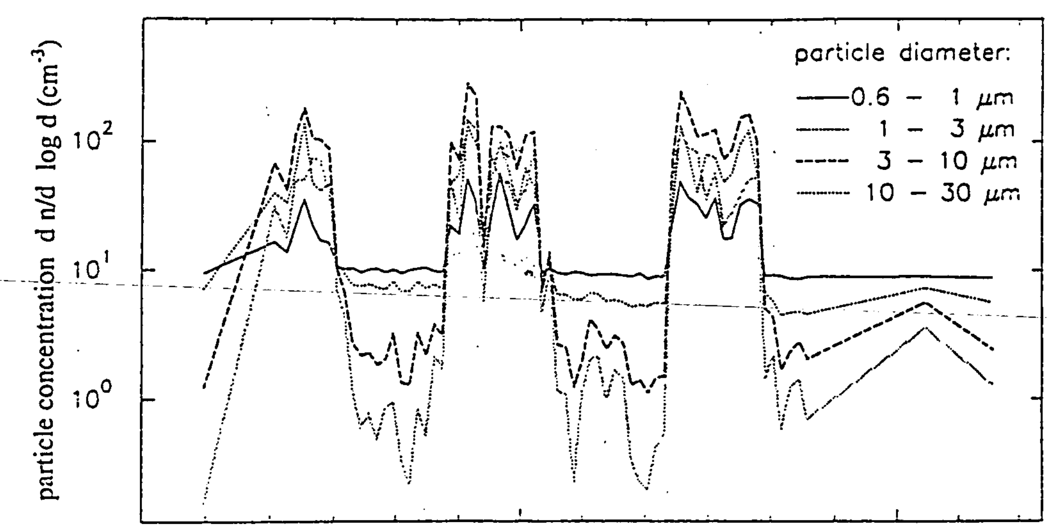

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Table 4 Mass specific ^{137}Cs activity concentration of airborne and soil particles of different particle size ranges during anthropogenic enhanced resuspension in Zapolie; in the last two rows the relation between the concentration in air and soil (enrichment factor) is given for the measurements in Zapolie and two other sites

Experiment	Mass specific ^{137}Cs concentration in air and soil (mBq g^{-1})			
	<2.0 μm	2–4 μm	4–7 μm	7–16 μm
13 May 1993 big tractor	370	160	74	71
22 May 1993 truck	290	430	220	550
24 May 1993 two trucks	640	340	320	330
25 May 1993 morning, small tractor	180	230	100	270
25 May 1993 afternoon, truck	810	640	145	360
May 1993 soil [12]	120	38	20	11
	Enrichment factor			
May 1993 Zapolie	3.8±2.2	9.5±4.9	8.6±5.0	28.8±15.7
Nevada test site [13]	3.6			
Bikini Atoll [13]	3.9			

Table 5 Dry deposition velocities during anthropogenic activities at Zapolie: each value refers to the average deposition to four "planchettes" (at heights 0.5, 1.0, 1.5 and 2.0 m) and the average aerosol concentration (measured at heights 1.0 and 1.8 m)

Date, time	Dry deposition velocity (m s^{-1})	Standard deviation (m s^{-1})
11.05.93. 12:15–14:40	0.036	0.009
11.05.93. 16:15–17:55	0.047	0.021
12.05.93. 11:20–15:00	0.040	0.021
12.05.93. 16:00–18:00	0.063	0.009
13.05.93. 09:40–13:00	0.018	0.007
13.05.93. 17:15–18:40	0.023	0.007
21.05.93. 12:30–16:30	0.009	0.003
22.05.93. 10:00–12:15	0.008	0.004
22.05.93. 12:15–16:20	0.006	0.001
23.05.93. 10:30–13:00	0.021	0.001
24.05.93. 15:30–18:30	0.035	0.005
25.05.93. 11:15–13:10	0.027	0.007
25.05.93. 16:00–17:10	0.033	0.011
Arithmetic mean	0.026 ± 0.016	

sented, summarizing three experimental conditions: periods of soil management, break periods and the total experimental period. For example, if we consider the mean concentration for the total experimental period, we find the maximum concentration in the large particle range (3–10 μm) and the minimum concentration in the fine particle range (0.6–1.0 μm). This can be explained by the fact that larger adhesive forces are found for the fine particles in comparison with the large ones, preventing atomising of the fine soil particles [11]. Averaging over the whole measurement period even blurs this effect, which can be seen by comparing the mean concentration of the harrowing periods only with the periods without any soil management. The mean concentration of large particles (3–10 μm) is four times and of giant particles (10–30 μm) twice the mean concentration of fine particles (0.6–1.0 μm). Without anthropogenic activity, the relation is inverse: the concentration of fine particles is three times the concentration of large particles and six times the concentration of giant particles. For giant particles, the coefficient of variation (standard deviation/mean concentration) is the largest, and the ratio of the maximum to the minimum concentration (N_{max}/N_{min}) is close to three orders of magnitude. For the fine particles, the coefficient of variation is the smallest, and (N_{max}/N_{min}) is smaller than one order of magnitude. During anthropogenic enhanced resuspension many large particles were created, which must be considered for radiological estimations.

In order to compare the radioactive loading of the airborne particles with the loading of the soil particles, the mass specific activity concentration of airborne particles was determined. From data of the Berner impactor (mass concentration) and PK impactor (activity concentration), specific concentrations during different experiments were calculated for the particle size ranges $d<2$ μm, 2 μm $\le d<4$ μm, 4 μm $\le d \le 7$ μm and 7 μm $\le d \le 16$ μm (Table 4). Soil measurements resulted in an empirical equation relating specific soil activity with particle size [12]. In Table 4, the specific soil activity concentrations are given for the same particle ranges as for the aerosol measurements. The aerosol measurements showed varying specific activities, with the lowest values generally in the range 4–7 μm and the highest values either in the range <2 μm or in the range 7–16 μm. The specific activity decreased with particle size. In all experiments and in all size ranges the airborne specific activity concentration was higher than the concentration in soil.

This enhanced radioactive loading of airborne particles is quantified in Table 4 by the enrichment factor, which is the ratio of the mass specific air concentration and the mass specific soil concentration. Comparing the enrichment factor of the different size ranges, the highest factor is found for large particles (7–16 μm) and the lowest for fine particles (<2 μm). Evidently, the enrichment of radioactivity on particles during agricultural activity discriminates against fine particles, which tend to adhere to large host ones. In the fine and coarse particle size ranges the enrichment is about a factor of 4–9. This is in agreement with results of resuspension measurements at atomic bomb test sites [13], where enrichment factors of ^{239}Pu were determined in the particle range <10 μm during mechanical disturbance of soil (Table 4).

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Estimation of dry deposition velocity

Deposition measurements were performed at four different heights in Zapolie. In accordance with the theory of the atmospheric surface layer for stationary conditions [7, 8], no differences in the deposition rates at the various heights were found. Typical values of dry deposition rates during wind-driven resuspension were 1.9–2.3 μBq m^{-2} s^{-1}.

The total deposition $P(x, y)$ at a position with coordinates (x, y) in the sampling time T is given by

$$P(x,y) \cong v_s \int_0^T q(x,y,z)\,dt \qquad (1)$$

where q is the air concentration and v_s (m s^{-1}) is the dry deposition velocity at the sampling height z. By measuring the deposition P and the concentration q during anthropogenic activities, the dry deposition velocity was calculated by means of Eq. (1). In Table 5 results are presented using the average deposition on plates at heights of 0.5, 1.0, 1.5 and 2.0 m and the average air concentrations measured at heights of 1.0 and 1.8 m. The mean deposition velocity of all experiments was 0.026±0.016 m s^{-1}. This value was calculated under the assumption of an uniform set of observations, e.g. similar meteorological conditions during the experiments, which explains the large uncertainty. The deposition velocities were measured at a roughness length z_0 of approx. 8–10 cm. The results agree with curves of deposition velocity given by Sehmel [11] for particle deposition on various solid surfaces at z_0=10 cm.

The mean deposition velocity can be used for estimating the mean particle diameter. According to Stokes law, the mean diameter of a spherical particle moving with a speed of v_s=0.026 m s^{-1} is roughly estimated to be $\bar{d}\approx 19$ μm. We can make the more realistic assumption that the dry deposition velocity v_s is the sum of two independent parts, the settling velocity w_g and the deposition velocity for adhesive processes bu_*. Then

$$v_s = bu_* + w_g \qquad (2)$$

where b=0.01 for particles with d>5 μm and natural dry grass [9], leading to a diameter range of $\bar{d}\approx$6.2–12.6 μm for the range of measured u_* (0.3–0.61 m s^{-1}). This is in agreement with the measured mean diameters in experiments 11–25 May 1993 presented in Table 1, where is in the range 5.6–8.7 μm with mean 7.1 μm.

Deposition velocities for the dry deposition of ^{137}Cs were measured in Goiânia, Brazil, as well [10]. In the numerous measurements in an urban area under different meteorological conditions, deposition velocities were observed in the range 1–30 cm s^{-1} with an average value of approximately 5–6 cm s^{-1}.

Discussion and conclusions

- Anthropogenic activities such as soil management or traffic on unpaved roads in contaminated areas increase the resuspension of radionuclides in the surface layer of the atmosphere.
- The size distributions of atmospheric ^{137}Cs particulate activity during these periods of enhanced resuspension showed a similar common shape with two maxima, the first in the 2–4 μm range, the second in the 12–20 μm range.
- In the fine particle size range (0.1–2.0 μm), 33%±6% of ^{137}Cs activity was found as the mean of all experiments.
- An estimation of the airborne plutonium concentrations in two experiments of anthropogenic enhanced resuspension showed a significant proportion of activity in the fine particle size range (36%–40%) and in the large particle range (approximately 20%).
- The analysis of the micrometeorological conditions during the experiments showed that particles with d=12–20 μm are subject to medium range transport during unstable and windy situations. This means that the large particles have to be considered not only on a local scale for inhalation dose assessment and transport of contamination but also on the meso scale.
- Measurement of the number concentrations of particles has shown that means for large particles (3–10 μm) and giant particles (10–30 μm) are, respectively, four times and two times larger than the mean concentration of fine particles (0.6–1.0 μm) during periods of soil management. This increase was a factor of about 40 for large and giant particles, but only a factor of approximately 3 for the fine particles. The variability of the concentration is higher for giant particles. During anthropogenic enhanced resuspension, predominantly large particles are injected into the atmospheric surface layer.
- The estimated radioactive loading of particles showed an enrichment of resuspended radionuclides compared with soil particles. The highest enrichment factor was found for large particles, the lowest for fine particles.
- Dry deposition velocities were estimated for the experiments with anthropogenic enhanced resuspension. The mean value of the dry deposition velocity of ^{137}Cs was 0.026±0.016 m s^{-1}, which is typical for particles with a mean diameter of 6–9 μm.
- The different size-resolved measurements of resuspended radioactive particles proved the importance of considering large and giant particles in the assessment of inhalation dose and spread of contamination in meso scale distances from the source of anthropogenic enhanced resuspension.

Acknowledgements This study was supported by the CEC under contracts no. COSU-CT92-0015 and COSU-CT93-0039 in the framework of the 'EC/CIS Agreement for International Collaboration on the Consequences of the Chernobyl Accident'. We are grateful for meteorological information from Dr. J. Watterson, AEA Technology, Culham, UK, and soil parameter measurements by Drs. F. Besnus and J. M. Peres, IPSN, Fontenay-aux-Roses, France.

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Book

NCAR
CU Boulder → due 4-22-00
QC 882.4
P74 1992

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REFERENCES FOR THE MRI PORTABLE WIND TUNNEL METHOD

Since the 1950's, the U.S. Department of Agriculture has used portable wind tunnels to measure total soil loss from wind erosion. Soil loss is dominated by creep (rolling) and saltation (bouncing). The USDA was not interested in fractional soil loss due to particle resuspension, because particle resuspension constitutes only about 1 percent of the total soil loss.

Development of the MRI Portable Wind Tunnel

In 1978 as the interest in air pollution grew, the MRI portable wind tunnel was constructed to provide a critical feature not present in the earlier portable wind tunnels: the ability to measure fine particle emissions. The MRI portable wind tunnel used a design that was scaled directly from a smaller version built by Dr. Dale Gillette, and a downstream particle sampling module was added to the wind tunnel design.

Dr. Gillette used his wind tunnel to study threshold velocities for wind erosion of arid soils. His justification for the appropriateness of the portable wind tunnel method was detailed in the following publication.

Gillette, Dale (1978). "Tests with a Portable Wind Tunnel for Determining Wind Erosion Threshold Velocities." ***Atmos. Environ.*** **12:2309.**

Documentation of Field Studies

Since its development in 1978, the MRI portable wind tunnel method has been used in field studies that characterized fine particle emissions from a variety of erodible surface materials. Some of these studies are described in the following publications:

Farber, R. J., B. M. Kim, C. Cowherd, Jr., et al., "New Approaches to Dust Mitigation in the Antelope Valley," Presented at the 92nd Annual Meeting of the Air and Waste Management Association, St. Louis, Missouri, June 1999.

Cowherd, C., Jr., "Wind Erosion Emissions of Fine Particles from Limited Reservoir Surfaces," Presented at the 50th International Symposium on Wind Erosion, Manhattan, Kansas, June 1997.

Cowherd, C., Jr., and M. A. Grelinger, "Advances in Estimating Fine Particle Wind Erosion Emissions from land Contamination Sites," Paper 95-TP55.07. Presented at the 88th Annual Meeting of the Air and Waste Management Association, San Antonio, Texas, June 1995.

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Cowherd, C., Jr., "Fugitive Dust Emissions," in *Aerosol Measurement: Principles, Techniques, and Applications*, K. Willeke and P. A. Baron, Eds., Van Nostrand Reinhold, New York, New York, 1993.

Cowherd, C., Jr., "Emission Factors for Wind Erosion of Exposed Aggregates at Surface Coal Mines." Paper 82-15.5. Presented at the 75th Annual Meeting of the Air Pollution Control Association, New Orleans, Louisiana, June 1982.

Cowherd, C., Jr., C. R. Hodgin, and D. D. Lane, "*In Situ* Measurement of Wind-Generated Particulate Emissions from Exposed Aggregates," Presented at the EPA 3rd Symposium on the Transfer and Utilization of Particulate Control Technology, Orlando, Florida, March 1981.

Cowherd, C., Jr., "Control of Windblown Dust from Storage Piles," *Environment International*, 6, 307-311, 1981.

Cowherd, C., Jr., T. Cuscino, Jr., and D. A. Gillette, "Development of Emission Factors for Wind Erosion of Aggregate Storage Piles," Paper 79-1.1. Presented at the 72nd Annual Meeting of the Air Pollution Control Association, Cincinnati, Ohio, June 1979.

Although more refined particle monitors have been incorporated into the MRI wind tunnel over the years, the basic method has remained intact.

Endorsement by USEPA

The MRI portable wind tunnel method has been endorsed by the U.S. Environmental Protection Agency as the preferred method for developing wind erosion emission factors for surfaces with "limited reservoir" erosion characteristics, such as those found in Rocky Flats soils. This is illustrated by the following publications:

U.S. Environmental Protection Agency. *National Technical Guidance Series Air Pathway Analysis Procedure for Superfund Applications.* Vol. II: *Estimates of Air Emissions at Superfund Sites.* EPA-450/1-89-002a, 1989.

Cowherd, Chatten, Jr.. *Background Document for AP-42 Section 11.2.7 on Industrial Wind Erosion.* EPA Contract No. 68-02-4395. Midwest Research Institute, July 1988.

Cowherd, C. Jr., G. E. Muleski, P. J. Englehart, and D. A. Gillette. *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites.* EPA Publication EPA/600/8-85/002. Washington, DC., U.S. EPA. 1985.

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Axetell, K., Jr., and C. Cowherd, Jr., "Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources," EPA Publication EPA-600/7-84-048; NTIS Publication PB84-170802, March 1984.

Other Portable Wind Tunnels

In 1990, MRI was contracted to build two reduced-scale portable wind tunnels for application to Owens Dry Lake, which is the largest single wind erosion source in the U.S. (110 sq. mi.). The reduced-scale wind tunnels used to map the erodibility of the dry lakebed are described in the following publications:

Cowherd, Chatten, Jr. *Wind Tunnel Comparability Study—Test Report.* Prepared by Midwest Research Institute for Great Basin Unified Air Pollution Control District, November 1993. .

Cowherd, C., Jr., and D. M. Ono, "Design and Testing of a Reduced-Scale Wind Tunnel for Surface Erodibility Determinations," Paper 90-84.6. Presented at the 83rd Annual Meeting of the Air and Waste Management Association, June 1990.

Other investigators have consulted with MRI in constructing portable wind tunnels for use in characterizing the fine particle emission potential of western soils. These include:

Dr. David James
University of Nevada at Las Vegas
Las Vegas, Nevada

Dr. Keith Saxton
United States Department of Agriculture
Spokane, Washington

Their portable wind tunnels are still being used in studies of the Columbia Plateau and areas around Las Vegas.

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RFCA Stakeholder Focus Group
Attachment B

Title:	August 8, 2001 Meeting Minutes
Date:	September 19, 2001
Author:	C. Reed Hodgin AlphaTRAC, Inc.
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RFCA Stakeholder Focus Group
August 8, 2001
Meeting Minutes

INTRODUCTION AND ADMINISTRATIVE

Please note, a participants list and all attachments mentioned herein for the August 8, 2001 Rocky Flats Cleanup Agreement (RFCA) Stakeholder Focus Group meeting were mailed and emailed on August 15, 2001.

Reed Hodgin of AlphaTRAC, Inc., meeting facilitator, reviewed the purpose of the RFCA Focus Group. Introductions were made.

Reed mentioned that the meeting minutes for the June 30, 2001 Focus Group meeting were electronically mailed out to the Stakeholders this day. He asked that the Focus Group look them over and let AlphaTRAC know of any corrections, additions, or deletions via email to Christine Bennett.

Ann Lockhart of the Colorado Department of Public Health and Environment (CDPHE) announced that she had brought copies of two reports produced for the Health Advisory Panel:

1. *Summary of Findings, Historical Public Exposures Studies on Rocky Flats, August 1999,* a nine year comprehensive study done by Radiological Assessments Corporation (RAC);

2. *Assessment Risks of Exposure to Plutonium, Revision 2, February 2000,* a technical report, also by the RAC, which changed their name to Risk Assessments Corporation

Christine Bennett noted that AlphaTRAC has copies of these reports and offered to make them available to anyone who is interested.

AGENDA

Reed reviewed the agenda for the Focus Group Meeting:

- RSALs: Task 3 – Parameter Discussion and Modeling Results
- Review of Peer Review Process for Task 3, Including Wind Tunnel Peer Review
- Clean-up Alternatives Matrix – Distribution of Draft Working Group Results

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CLEAN-UP ALTERNATIVES MATRIX - DISTRIBUTION OF DRAFT WORKING GROUP RESULTS

Ken Brakken of the U. S. Department of Energy (DOE) talked about the Cleanup Alternatives Matrix being developed by a working group. He noted that a draft matrix was being distributed at the meeting. The matrix lists cleanup alternatives on the vertical axis and outcomes along the horizontal axis. The boxes will be filled in with information about how each alternative affects each outcome.

Ken asked that the members of the Focus Group review the draft matrix and provide comments back to the working group.

RSALS: TASK 3 - PARAMETER DISCUSSION AND MODELING RESULTS

Reed listed objectives for today's discussion on parameters and modeling results:

- Get information on key parameters
- Get information on first results
- Get information on path forward
- Get clarification and understanding of key parameters
- Provide feedback on key parameters
- Get clarification / understanding of first modeling results
- Set a path forward for next discussion

Reed stated that the focus of discussion at this meeting would be technical, rather than policy, issues. He indicated that the Focus Group would first identify and resolve all of the technical issues that it wished to. Once the technical bases of the RSAL calculations were well understood and feedback had been provided to the agencies, the policy discussion could begin.

Steve Gunderson of CDPHE introduced the technical presentation by the agencies. He indicated that he would provide and describe the first modeling results to the Focus Group. Then, Tim Rehder of EPA would describe the two land use scenarios for which calculations had been completed. Finally, Bob Nininger of Kaiser-Hill would make a presentation on key parameters.

First RSAL Modeling Results

Steve Gunderson passed out a matrix showing the first RSAL modeling results. He stated that preliminary results had been calculated for two land use scenarios: wildlife refuge worker and rural resident. He noted that potential RSAL values had been calculated for the 25 mrem dose limit specified in the State's Radiation Control Regulations and for three risk values (10^{-4}, 10^{-5}, and 10^{-6}) from the risk range specified in the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). The RSALs Working Group applied the RESRAD model to the dose calculations and the standard U. S. Environmental Protection Agency (EPA) risk equations (the RAGS model) to the risk calculations. The dose and risk values are for Plutonium with Americium included, using the sum of ratios method.

The results are shown with the number of digits that were produced by the model. The actual precision of the results is one or two significant digits - the final numbers will be rounded to reflect the actual precision in the modeling results. Finally, Steve noted that the values shown in the matrix represent the 95th percentiles from the ranges that were calculated for each box in the matrix. This means that 95% of the projected doses or risk in the distribution were lower than the value shown and 5% were higher than the value shown.

Steve noted the wide range in potential RSAL values corresponding to the CERCLA risk range. RSAL values for the wildlife refuge worker ranged from 5 to 512 pCi/g, while values for the rural resident ranged from 2 to 190 pCi/g. He stated that this two order of magnitude range relating to a two order of magnitude risk range was expected.

Steve also pointed out that the dose-based values (875 pCi/g for the wildlife refuge worker, 223 pCi/g for the adult rural resident, and 250 pCi/g for the child rural resident) all exceed 10^{-4} risk and were thus outside the CERCLA risk range.

Steve emphasized that the primary purpose for the matrix was in establishing a surface RSAL for Rocky Flats. He also said that there had been discussion among the agencies that the matrix could serve three other purposes as well. First, the matrix could be used to establish tier levels for RSALs. He said that there would have to be discussion, including discussion by the Focus Group, on how tiers could contribute to the cleanup process. He further stated that the matrix could be used to help define As Low As Reasonably Achievable (ALARA) goals for removal beyond required levels. Finally, the matrix could be used in another ALARA-like activity to establish limits for institutional controls (e.g., "do not dig" areas) where contamination exists, but at a level too low to trigger cleanup action.

Steve said that the Working Group was now turning its focus to calculating the results for the other three scenarios in the matrix. Calculations will also be performed for Uranium (there are some hot spots at Rocky Flats) once the Plutonium / Americium calculations are complete - probably in the next month or two.

Land Use Scenarios

Tim Rehder next briefed the Focus Group on the two land use scenarios for which calculations had been completed: wildlife refuge worker and rural resident.

Tim introduced the wildlife refuge worker as the likely anticipated future land user. He indicated that this land user would be a full time worker on site whose activities would include but not be limited to building trails, installing fences, and conducting controlled burns.

Tim introduced the rural resident land use as a good candidate for the ALARA goal, since the agencies consider it the most likely land use in the event of institutional control failure. The key characteristics of the rural resident are its location on the most contaminated areas, the large ranchette-sized property allowing horses and other dust-disturbing animals, and a very large garden with large crops and a heavy dependence on home-grown fruits and vegetables.

Key Parameters

Bob Nininger made a summary presentation and responded to questions concerning key input parameters for the RSAL modeling.

Bob stated that more than 60 input parameters had been evaluated with values developed for input to the RSAL models (RESRAD and RAGS). He said that most of these parameters were not sensitive - changes in the parameters did not cause significant changes in the model results. Single values were typically used as inputs for these parameters.

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Bob said that there were a limited number of parameters to which the model was very sensitive. Variations in these "key parameters" could cause significant changes in model results. Single value inputs were used for those key parameters that were well characterized and that varied little. Probability distribution functions (distributions) were employed for those key parameters that either had large uncertainties or varied over a large range. Bob noted that the upper end of the distributions were most important as those portions contributed most to the 95th percentile in the final results.

Bob identified four key parameters for use in the RSAL modeling:

- Soil ingestion,
- Inhalation rate,
- Mass loading, and
- Exposure frequency and exposure time.

Bob indicated that he would also discuss Dose Conversion Factors (DCFs) which, while not strictly model input parameters, involves an important choice which significantly affects modeling results.

Dose Conversion Factors

Bob stated that the RSAL Working Group had held extensive discussions on the choice of DCFs. The Working Group decided to apply the new International Council on Radiation Protection and Measurements (ICRP) 68/72 DCFs, rather than the historically used ICRP 26/30 DCFs, because:

- The ICRP 68/72 DCFs represent the latest consensus thinking by the international scientific community,
- In-tissue weighting factors have been updated,
- The methodologies for lung and ingestion pathways have been significantly changed, and
- Age-dependent DCFs are now available.

Two significant results of this choice are that the soil ingestion and plant ingestion pathways have increased in importance, while the inhalation pathway has decreased in importance.

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Bob also noted that DCFs associated with the "Moderate" clearance class would be used rather than the "Slow" clearance class, and that estimated doses would be higher as a result.

Inhalation Rate

Bob stated that distributions had been created for breathing rate. EPA studies and data compilations formed the basis for the data distribution for the rural resident (adult and child). An unbounded lognormal distribution had been found to fit the data best. The arithmetic mean and standard deviation for the adult rural resident were 16.2 and 3.9 m^3/day, while the arithmetic mean and standard deviation for the child rural resident were 9.3 and 2.9 m^3/day. Bob emphasized that the arithmetic means do not represent the most important breathing rate values, as the values that would relate to the 95^{th} percentile doses and risks would come from the tails of the distributions. Bob noted that the breathing rate is lower for the child primarily because of lower lung capacity.

The Working Group used a risk assessment performed for the Rocky Mountain Arsenal as the basis for the data distribution for the Wildlife Refuge Worker. The group found that a beta distribution best fitted the breathing rate data for this land use scenario. The beta distribution was characterized by a minimum breathing rate (1.1 m^3/hr), and maximum breathing rate (2.0 m^3/hr) and two shape factors.

Bob also showed breathing rate values as used in the RAC study.

A member of the Focus Group asked if the greater number of breaths per minute for a child had been taken into account. Bob responded that this effect had been considered.

A member of the Focus Group asked if the RAC number quoted (10,800 m^3/year) was for a resident rancher. Tim Rehder responded that the RAC number was for a resident rancher. There was a point made that the breathing rate for a resident rancher should be higher than that for a resident.

The discussion continued with a focus on comparing breathing rates among the 1996 RSAL calculations, the RAC study, and the current analysis. The group and agencies found it difficult to compare the current distributions against the point values used in 1996 and by RAC. The agencies agreed to find a way to present an "apples-to-apples" comparison and bring this back to the Focus Group.

Soil Ingestion Rate

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Bob stated that the Working Group had reviewed a number of soil ingestion studies and had determined that the most appropriate study was the Calabrese study conducted in Montana. The key to the particular usefulness of this study was the careful control and monitoring of inputs and outputs from the test subjects. Bob stated that the study involved 63 test subjects.

The soil ingestion data for children based on the Calabrese study were best fit by a bounded lognormal distribution. Bob noted that the mean of the distribution is 16.6 g/year with a standard deviation of 40.9 g/year and upper and lower bounds of 1 and 365 g/year. Bob noted that the top end of the range represented a "Pica child," ingesting far more soil each year than a normal child.

Bob next summarized the data used for adult soil ingestion. The agencies emphasized that the Calabrese study had been intended to characterize soil intake by children. A limited amount of adult data had been gathered for confirmatory purposes. The Working Group determined that the adult dataset was not sufficiently large to use as the basis for either a point value or distribution. As a result, the RSALs Working Group decided to apply the EPA default value of 100 mg/day for the RSAL modeling. A model input value of 350 g/year was calculated based on an assumed overall residence time of 350 days / year.

Bob also noted that input values for the RESRAD model were multiplied by a factor of 3 to account for a model artifact that allowed soil ingestion only 8 hours per day.

Mass Loading

Bob provided a brief summary of the mass loading parameter, as more detailed briefings had already been provided to the Focus Group. Bob indicated that the RSALs Working Group had examined historical particulate air quality monitoring data for Rocky Flats, with a median concentration of 11 μg/m^3. This represented a very clean (dust-free) atmosphere. While this distribution is representative of conditions while Rocky Flats was operational and in shut down, it may not be representative of future conditions under other land uses. So, the Working Group decided to build a distribution based on the median particulate air quality conditions around the state of Colorado. This data distribution produces a median concentration of 21 μg/m^3, almost twice as high as the historical conditions at Rocky Flats.

The results of the wind tunnel experiments were used to characterize atmospheric particulate loadings following a wildfire or prescribed burn. Bob noted that this was an important input to the mass loading parameter, as the fire scenarios dominated mass

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loading along the tail of the mass loading distribution (the portion of the distribution with the greatest influence on the 95th percentile RSAL results).

Site-specific meteorological data were analyzed to determine historical precipitation patterns at the site. The data were used to define a dry period for Rocky Flats.

Site-specific particulate monitoring data were used to characterize particle size distributions in airborne dust. The fraction of particulates less than 10 µm in diameter (PM^{-10}) was used for modeling the inhalation pathway, while the total suspended particulate (TSP) fraction was used for the soil ingestion and plant intake pathways.

A member of the Focus Group asked for more detail on the use of the wind tunnel experiments and the evaluation of fires in the modeling. Bob responded that the upper 10% of the mass loading distribution is dedicated to fires, as it is assumed that a fire could occur 10% of the time. Fire frequency is dominated by prescribed burns, which are assumed to occur much more often than the historical incidence of wildfires at the site.

A member of the Focus Group asked if direct emissions from lightning strikes had been considered. Bob responded that the disturbance from a lightning strike impacting the soil was not considered. His feeling was that this was appropriate as such strikes were infrequent and affected a very small area. The real influence of lightning strikes shows in the frequency of wildfires.

There was a discussion of site-specific meteorology. Bob stated that meteorological data were available for the site back to 1953, but that all of the years were not used due to completeness of data and quality considerations. In response to a question about using state-wide precipitation data, Bob confirmed that site-specific meteorological data had been used exclusively.

Exposure Frequency and Exposure Time

Bob stated that the basic assumption on exposure frequency for the rural resident is that the person would be indoors 85% of the time and outdoors 15% of the time while at home. The values were based on literature surveys of the behavior of residential occupants. A triangular distribution was used to represent this in the models. Slightly different input parameters were developed for the RESRAD and RAGS models due to different model input requirements.

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The Wildlife Refuge worker was assumed to be onsite 8 hours per day, with approximately 50% of the time spent indoors and 50% of the time spent outdoors.

A member of the Focus Group asked if the effects of high wind events on Wildlife Refuge Workers had been calculated. Bob responded that high wind events were incorporated in the mass loading. He emphasized that high wind events were not treated as individual occurrences but were included in the annual mass loading values.

Group Discussion

Bob concluded his presentation with a summary and opened the floor to discussion.

A member of the Focus Group asked what level of particulate concentration would be uncomfortable to breathe. The response was about 125 $\mu g/m^3$. It was emphasized that the 125 $\mu g/m^3$ value was associated with a short term exposure, while the values used in the RSAL modeling were annual averages.

The group discussed the fire scenario further. The agencies noted that the scenario assumes that the entire site is subjected to a controlled burn every 10 years; thus the contaminated area burns every 10 years.

The seasonal differences in fire impacts were discussed. The scenario considers that there will be slower regrowth following a prescribed burn in the fall as compared to a prescribed burn in the spring. A multiplier is used for mass loading due to prescribed burns in the fall.

It was noted by the agencies that the influence of the fire on mass loadings dominated the first year following the fire. It was also noted that there would be some smaller elevation of mass loading in the second year following the fire due to loss of thatch.

There was a discussion on the influence of time spent indoors vs time spent outdoors. The agencies indicated that exposures would be lower indoors because of shielding from gamma exposure and due to slow infiltration of outdoor air carrying contaminated particulates. A 70% shielding factor was assumed for both gamma shielding and infiltration (a note was later made that the gamma shielding factor was 60%). This means that a person indoors receives 70% of the exposure that would be received outdoors. A residence-like building was considered with windows that would open, as opposed to an office building with recirculated air and filtration.

The group discussed the differences between frequency distributions and cumulative frequency distributions and how the distributions were separated into bins for input to the models.

There was further discussion of how the state-wide particulate air quality data were used with Rocky Flats data to generate a mass loading distribution and how the fire data were added to the distribution.

A member of the Focus Group expressed concern that the soil ingestion data from the Calabrese study might not be representative of the high wind events that occur at Rocky Flats. He was concerned that more soil would be ingested during high winds. There was discussion among the group and with the agencies about the inhalation of dust during high wind events. It was noted that much of the dust resuspended during high winds is in the form of large particles, which would generally not penetrate far into the breathing pathways before being trapped and removed. It was pointed out that a conservative assumption was being made in this regard - that all particles less than 10μm in diameter would penetrate the lung system and cause exposure, while in practice only particles with diameters of 2.5μm or less penetrate far enough. The member of the Focus Group noted that his concern was about soil ingestion - both direct introduction of dust into the mouth and then swallowed during high wind events, and the swallowing of contaminated dust in mucus from the nose and upper respiratory tract.

AGENDA

Reed noted that time had run out before there was an opportunity to discuss the Task 3 Peer Review and Wind Tunnel studies Peer Review and promised to place this topic in a priority position on the agenda for the August 22, 2001 Focus Group meeting. The Group agreed to focus on technical issues associated with the RSAL modeling at the next meeting. The members of the Focus Group agreed to review the handouts from the key parameters discussion and identify specific technical questions to be addressed on August 22, 2001. The members agreed to submit their questions to AlphaTRAC by August 17, 2001 to be compiled into a list for discussion. An update on RSAL modeling results was requested, along with a request for a briefing on pathway contributions to RSAL results.

ADJOURN

The meeting was adjourned at 6:30 p.m.

RFCA Stakeholder Focus Group
Attachment C

Title:	April 27-28, 2001 RSALs Computer Modeling Workshop Outcomes
Date:	September 19, 2001
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Stakeholder Workshop on Computer Modeling and Parameter Selection for Radionuclide Soil Action Levels at Rocky Flats

April 27 – 28, 2001

Westminster, Colorado

Workshop Summary

Introduction

In 1996, the Department of Energy (DOE), the Colorado Department of Public Health and Environment (CDPHE), and the Environmental Protection Agency (EPA) established interim radionuclide soil action levels (RSALs) to guide the cleanup at Rocky Flats as part of the Rocky Flats Cleanup Agreement (RFCA) signed by the three agencies. When these RSALs were announced, concern arose among members of the stakeholder community that the numbers were too high to provide for the health and safety of current and future residents. In 1998, the Department of Energy agreed to provide funding for an independent assessment of the RSALs.

The independent assessment was overseen by a group of community members named the Rocky Flats Radionuclide Soil Action Levels Oversight Panel (RSALOP). In a competitive bidding process, the Oversight Panel selected Risk Assessment Corporation (RAC) to conduct the study. After 18 months, RAC completed its work and recommended RSALs significantly lower than those established by the agencies in 1996.

Early in 2000, DOE, CDPHE and EPA established the RSAL Working Group comprised of technical representatives from their agencies to begin a comprehensive review of the RSALs as part of the overall annual review process for RFCA. The Working Group would review all relevant new information, including the work performed by RAC, to determine what modifications, if any, needed to be made to the RSALs. To incorporate public participation in this review, as well as other issues related to RFCA, the agencies also established the RFCA Focus Group. This group comprised of community members, many of whom served as part of the RSALOP, meets twice a month to discuss RFCA and RSAL issues.

During the course of these meetings, the participants began to discuss the need for a series of stakeholder workshops to address issues related to the RSALs. Concurrently, the Rocky Flats Citizens Advisory Board (RFCAB) issued a recommendation to DOE and the regulators requesting that they sponsor a workshop, focusing on computer modeling and input parameter selection. DOE agreed to sponsor the workshop, and provided funding to RFCAB to organize and host the workshop. An agenda planning committee comprised of community and agency representatives, as well as outside subject matter experts, developed the agenda and presentations delivered at the workshop.

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Goals of the Workshop

The workshop organizers determined that the workshop would have several goals. First, there would be education of the stakeholder community. The organizers would invite a panel of subject matter experts from around the country to present information related to the use of computer models and selection of input parameters for application in the cleanup of radioactively contaminated sites. Second, there would be an opportunity for dialogue between the expert panel and members of the RSAL Working Group. It was hoped that the outside experts could bring their relevant knowledge and experience to provide input to the Working Group members. Finally, there would be an opportunity for the workshop attendees to ask questions and gain opinions from both the expert panel and Working Group members on computer modeling and parameter input issues.

The Workshop Agenda

The Workshop Agenda was divided into four parts to meet the three general goals established for the workshop. Part 1, *Foundations for Development and Use of Computer Models to Determine Soil Cleanup at Radioactively Contaminated Sites*, would serve as the education component to lay a foundation of understanding for the workshop attendees. Information presented in the initial presentations was reinforced by the examination of two case studies on previous work done related to development of soil action levels using computer models.

Part 2, *Application of Models for Use at Rocky Flats*, provided more of a focus on specific modeling issues related to Rocky Flats. After initial presentations by members of the expert panel and the Working Group, this part of the workshop allowed for dialogue between members of the two groups, as well as provided an educational opportunity for the workshop attendees. The first day of the workshop ended with the group identifying and prioritizing topics they would consider on the second day.

The second day began with Part 3, *Key Modeling Issues of Concern at Rocky Flats*. The discussion of issues identified from the previous day included brief presentations by some members of the expert panel and the Working Group. Again to meet the goals of the workshop, there was an extended opportunity for dialogue between the two groups, as well as opportunity for the workshop attendees to join the conversation with their questions and comments.

The workshop concluded with Part 4, *Where do we go from here?* In this part each of the expert panel members and the Working Group representatives presented brief comments outlining lessons learned, next steps and other impressions of the workshop. Workshop attendees also provided their statements.

The Workshop Presenters

The invited panel of experts and members of the Working Group who provided presentations during the workshop included the following individuals.

Expert Panel Members:

Dr. Kathryn Higley: A certified health physicist, Dr. Higley currently is an Associate Professor in the Department of Nuclear Engineering at Oregon State University. She holds a Ph.D. in Radiological Health Sciences from Colorado State University. Her fields of interest include human health and ecological risk assessment, environmental pathways analysis, environmental radiation monitoring, radiochemistry, and environmental regulations. Dr. Higley performed risk assessment modeling at the Johnston Atoll in the South Pacific, a Cold War missile launch site for atmospheric testing of nuclear weapons. This site has plutonium soil contamination from various mishaps, including a failed missile launch, and faces cleanup decisions similar to Rocky Flats.

Charley Yu: Dr. Yu is the Program Manager and Principal Investigator for the RESRAD Development Program in the Environmental Assessment Division of Argonne National Laboratory. He holds a Ph.D. in Nuclear Engineering from Pennsylvania State University. Dr. Yu also is a certified health physicist and has been invited to present numerous seminars and workshops internationally on the topics of soil cleanup criteria, radioactive waste disposal, multiple pathway analysis, and radiological risk assessment.

John Till: Dr. Till is the President of Risk Assessment Corporation and is quite familiar to the Rocky Flats community, having conducted the independent assessment of the radionuclide soil action levels for Rocky Flats beginning in 1998. His firm specializes in conducting independent research concerning environmental risk analysis for radionuclides and chemicals in the environment. In 1997 he was elected a member of the International Commission on Radiological Protection (ICRP). He also serves as a member of the U.S. National Council on Radiation Protection and Measurements (NCRP). Dr. Till received his Ph.D. from Georgia Institute of Technology.

Art Rood: Mr. Rood received his Masters Degree in Health Physics from Colorado State University. His work has been primarily in the field of environmental contaminant transport modeling, and dose and risk assessment. Mr. Rood has completed studies at numerous DOE facilities including Rocky Flats, Idaho National Engineering and Environmental Laboratory, the Hanford Reservation, and most recently the Los Alamos National Laboratory studying atmospheric releases following the May 2000 fire. Currently he is working on a user-friendly interface that will allow members of the public to receive a cancer risk estimate based on their own exposure history to DOE sites at Hanford and Rocky Flats.

Kathleen Meyer: Dr. Meyer's areas of expertise include cancer research, historic evaluation of past radionuclide and chemical releases, and risk assessments of radionuclides and chemicals. She received a Ph.D. in Radiological Health Sciences from Colorado State University. She has examined past releases from numerous DOE facilities including Fernald in Ohio, Savannah River in South Carolina, Rocky Flats, and the Idaho National Engineering and Environmental Laboratory.

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RSAL Working Group Representatives:

Bob Nininger: Dr. Nininger holds a Ph.D. in Physics from the University of North Carolina. He currently works for the Rocky Flats site contractor, Kaiser-Hill, as head of the Environmental Media Management Group. A former academician, Dr. Nininger once taught physics and served as an Assistant Dean. His research career has included work at USEPA in the Aerosol Research Branch and Special Techniques Branch of the Environmental Sciences Research Laboratory. He also worked at Los Alamos National Laboratory where his duties included the design of special air monitoring research projects and the oversight of proprietary air-model development and modeling services.

James Benetti: Mr. Benetti has spent the past 19 years working as a health physicist for state and federal government agencies. Currently he works for EPA in Las Vegas where his principal responsibilities have included providing technical support to Superfund in implementing the provisions of CERCLA and RCRA at radiologically contaminated sites. He worked extensively on the WIPP certification process. Mr. Benetti holds a Masters Degree in physics from the University of Wisconsin, Madison.

Several additional individuals provided significant input during the workshop. They were Dr. Helen Grogan, a member of the Risk Assessment Corporation team and S.Y. Chen with Argonne National Laboratory. Additional participants from the RSAL Working Group included Susan Griffin and Tim Rehder with EPA; John Rampe with DOE; and Steve Gunderson with CDPHE.

A Summary of the Workshop

The following pages contain a summary of the workshop. Individual summaries are provided for each of the four workshop parts. In most instances, summaries of the discussions are without attribution unless it was judged necessary for better comprehension of the comment or question and response. For those desiring a more complete record of the workshop beyond this summary, both an audio and videotape are available.

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PART I: Foundations for Development and Use of Computer Models to Determine Soil Cleanup at Radioactively Contaminated Sites

After opening remarks, presented by John Rampe (DOE-RFFO), the morning session began with six presentations on the fundamentals of computer models and their application to contaminated sites. The first five presentations covered the basics of risk analysis, history of modeling, modeling concepts, and the development of the RESRAD model. The participants then engaged in an open discussion, first among the panelists, then with the audience. Next, Dr. John Till (RAC) and Dr. Kathryn Higley (OSU) presented case studies, using Rocky Flats and the Johnston Atoll. Finally the morning session wrapped up with another open discussion.

Presentation I: *Basics of Risk Analysis to Determine Cleanup Levels*: John Till, Risk Assessment Corporation

Dr. John Till gave the first presentation on the basics of risk analysis. Using dose to assess risk, Dr. Till provided his definition of dose:

Dose = (**S** x T x E x DF)uvcpm, where:
S = **source term (RSAL)**
T = transport of contaminants
E = exposure scenarios
DF = does conversion factors
u = uncertainty
v = validation
c = communication of results
p = public participation
m = management and decision making

Although, risk is not the approach that will be discussed in this workshop for determining soil action levels for radiological contaminants, Dr. Till suggested that it should be. His definition of risk differs slightly from dose:

Risk = (S x T x E x DF x RF)uvcpm, where

RF = risk conversion factors

In 1999, the RAC study looked at dose then converted to risk for comparison.

Finally, Dr. Till discussed the uncertainty of the final soil action levels and some parameters, such as transport and exposure scenarios.

He concluded by recommending that the working group develop soil action levels in an unbiased and independent manner, without preconceived ideas of what the goal number should

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be. He also suggested that "best science" should be used to back up every decision that might influence the outcome of the soil action level.

Presentation 2: *History of Model Development*: Kathryn Higley, Oregon State University

Dr. Kathryn Higley gave the second presentation on the history of model development. She provided an introduction to scientific models and explained their different applications in radiological assessments, such as for screening, compliance, performance assessment, and/or scientific information. There are several rationales for using models to determine soil action levels. First, the models provide an alternative method to the risk assessment for evaluating dose. Second, models are the best and least expensive alternative to sampling. Finally, models allow for predictive, "what if" forecasting. The purpose of the computer model is to quantify the relationship between the contaminant release, contaminant transfer or pathway, and potential impact to humans and the environment. Computer models can be simple or complex, depending on the specific needs. The more data that is input into the model, the more complex the model becomes. Simple models tend to overestimate the risk, which makes them suitable for screening purposes, but impractical for determining cleanup levels. Regulations may specify a specific model to demonstrate compliance. This provides a common basis for regulators to evaluate multiple sites. This also simplifies the regulatory analysis. Unfortunately, regulatory prescribed models do not always address site-specific considerations.

Another type of model can be used to analyze dose. These more sophisticated models can reconstruct dose retrospectively, provide a quantitative evaluation of dose, and/or provide site-specificity. Examples include GENII and PATHWAY.

Models can be used to assess potential future performance and the potential for release. RESRAD is an example of a performance assessment model.

In order to select the appropriate model, the reviewer must carefully consider the supporting documentation, quality control, verification, validation, and general acceptance and use. A screening model is selected as a screening tool during the initial stage of the problem analysis. Compliance models are selected when regulations prescribe them. Sophisticated models are best for sites with potentially significant impacts.

In conclusion, the simplest models are advantageous since these models are conceptually straightforward, results are easy to verify, and they provide a conservative estimate of dose.

Presentation 3: *Scenarios, Parameters, and Models*: Jim Benetti, EPA

Mr. James Benetti gave the third presentation on modeling concepts: scenarios, parameters, and models. He emphasized that the factors that impact the RSAL lie outside the particular computer model, such as the scenario assumptions and the parameter choices. Therefore, the distinction between the model concepts is important to understand. Scenarios are assumptions about human behavior and natural events for future site use. These primarily involve assumptions about behavioral and metabolic parameters. Parameters are the bridge between scenarios and the model. Parameters represent the features of the scenario, which are presented to the model as numbers. They are conveniently categorized as physical, behavioral, and metabolic. Sensitive parameters strongly affect the calculation results. The model is a set of formulas or "number crunchers." The formulas approximate reality. The model takes input numbers or distributions, performs calculations in prescribed ways, and displays output in prescribed ways. In order to have confidence in the model, the results must be compared to reality and quality assurance documentation must be reviewed. The quality assurance aspects of the model must be evaluated against the appropriate standard, such as NQA 2.7. Validation for long-term risk modeling is rarely possible. Therefore, adequate verification, testing, benchmarking, and configuration control must suffice.

Sensitive parameters may include residence times (behavioral), soil ingestion rates (metabolic), mass loading (physical), and/or gut uptake fraction (dosimetric).

Presentation 4: *Development and Application of the RESRAD Model*: Charley Yu, Argonne National Laboratory

The fourth presentation, by Charley Yu, covered the basics of the RESRAD model. RESRAD is a computer model, developed by DOE, to calculate site-specific residual radioactive material guidelines, or action levels (RSALs). RESRAD calculates the dose and excess lifetime cancer risks to maximally exposed individuals or members of a critical population group. The RESRAD model was first developed in the early 1980's and developed into the first draft code for IBM mainframes in 1987. The RESRAD model has been further developed and improved since that time and is cited in DOE Order 5400.5 and Title 10 of the Code of Federal Regulations, Part 834. RESRAD has a strong record of application. In addition to DOE, the Nuclear Regulatory Commission (NRC) and the EPA also support RESRAD. RESRAD has an international and broad national customer base. To date, Argonne National Laboratory has conducted 120 workshops on RESRAD.

RESRAD has six codes: RESRAD Offsite, RESRAD Build, RESRAD Chem, RESRAD Baseline, RESRAD Ecorisk, and RESRAD Recycle. The major features of RESRAD include multimedia pathway analysis, multiple exposure scenarios, and sensitivity/uncertainty analysis to identify key parameters. RESRAD is easy to install, easy to use, and has numerous technical support manuals.

Dr. Charley Yu used the multiple scenario analysis to demonstrate the RESRAD model. He showed how to simulate current and plausible future use scenarios. One or more exposure pathways can be added or suppressed. Occupancy factors and consumption parameters may be tailored according to the scenario being simulated. Typical scenarios include, but are not limited to, industrial, recreational, residential, and subsistence farming.

Next, Dr. Yu explained the quality assurance/quality control process, verification and validation, and results from a validation study. He also referenced six benchmarking studies that were conducted between 1990 and 1999 and 14 technical support documents. More information is available on the RESRAD website: http://web.ead.anl.gov/resrad.

Discussion of the Presentations

Discussion between the expert panel and the Working Group:

- Question: What are the benefits of benchmarking? Response: Benchmarking is important to detect simple errors in the code. However, different results don't necessarily indicate that the code itself is the one in error.

Open question and comment period:

- Comment: The terms model and code should be differentiated. Response: RESRAD is a code and benchmarking looks at pieces of the code. A code is a combination of a number of different models.
- Question: Are scenarios also validated? Response: Scenarios used for historical purposes can be validated (i.e. interviews with previous employees). Validation for future scenarios is difficult for behavioral parameters. The EPA applies historical and current data to future scenarios.
- Question: Has the benchmark testing of RESRAD 6.0 version been completed? Response: Yes, the benchmarking test was done. The deterministic part of RESRAD 6.0 is the same as RESRAD 5.82. The modified probabilistic portion, or the uncertainty part, has been tested by hand calculations.
- Question: How valid are the previous RSAL calculations? Response: The reason the regulators are reevaluating the RSAL is because some people question the parameters that were used the first time. Sensitive parameters vary the results significantly. Don't let us mislead you that we can come up with numbers to two or three significant figures. We are not that good.
- Question: Were various changes to the RESRAD code, made over the years, significant? Response: The RESRAD website lists all the modifications to different codes. The inhalation area factor and the external dose for soil contamination have been updated based on recent scientific information. The future changes will include updating the EPA risk coefficients when they are published.
- Question: Does RESRAD consider health effects other than cancer? Response: Cancer is the only health effect considered. Miscarriages, for example, are not considered. These other health effects are caused by very high levels of exposure, not the low levels addressed by RESRAD.
- Question: Was RESRAD 6.0 verified using NQA 2.7? Response: NQA 2.7 was followed when the code was developed. However, several specific and equivalent quality assurance guidance documents were used to verify RESRAD 6.0. NQA 2.7 is more general.
- Question: How does RESRAD consider the timing factor of the dose calculation? Response: RESRAD calculates an annual dose, but will calculate to a specific time period (e.g., two months). The code will integrate that dose over a year for the calculation.
- Comment: Validation is impossible. Response: Validation isn't perfect. You can't recreate the real world with mathematical equations and go out a check it. It is impossible to validate models, but applications of models can be validated.
- Comment: RESRAD should be modified to consider sensitive individuals. Response: First, from the risk perspective, risk is a component of exposure and toxicity. Since the

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exposure varies by person (i.e., people drink different amounts of water, live different amounts of time, etc.) the point estimate approach calculations are based on the reasonably maximum exposure. In a probabilistic determination, the entire spectrum is considered. For toxicity, the risk assessment considers other health effects, besides cancer effects, whichever one causes effects at the lowest level in the most sensitive individual. Thus the model considers individuals that receive the highest exposure and the greatest effects.

<u>Presentation 5: *Case Study: Application of Risk Analysis at Rocky Flats*</u>: John Till, Risk Assessment Corporation

Dr. John Till presented a case study on Rocky Flats. In 1999, Dr. Till's firm, Risk Assessment Corporation (RAC), was hired to review DOE's RSAL calculations, which were finalized the previous year. RAC applied the same version of RESRAD, Model 5.82, as DOE. However, RAC input different parameters. One sensitive parameter, particulate resuspension, dramatically impacted the RSAL result. RAC used available environmental data and considered resuspension in the case of a significant wildfire. RAC also applied the most conservative scenario, the resident rancher to their calculations. The RAC analysis did not consider costs, health and safety risks, institutional controls, risks associated with prescribed dose limits, background radiation, and community values.

<u>Presentation 6: *Case Study: Evaluation of Potential Human Risks at Johnston Atoll from the Presence of Plutonium Contamination*</u>: Kathryn Higley, Oregon State University (OSU)

Dr. Kathryn Higley presented a case history of the Johnston Atoll cleanup. Since 1934, Johnston Atoll has been used by the U.S. Military as an airbase. Nuclear weapons testing occurred during the 1950's and 60's. In 1962, four nuclear missile launches failed, causing plutonium contamination of Johnston Island. Although some "spot cleaning" was performed between 1964 and 1978, actual cleanup did not begin until the 1980's. Today, the site remains relatively barren, except for approximately 1,200 military employees.

Oregon State University participated in the cleanup by providing technical assistance on site characterization, risk assessment, laboratory analysis, instrument modeling, and statistical sampling. The 1998 risk assessment focused on the probable pathways of exposure (terrestrial exposures only) within a 1,000-year timeframe. The geological features of the radiological control area consisted mainly of highly permeable crushed coral and sediments. The contaminants of concern included plutonium and americium. The risk assessors selected four potential anticipated future users for their assessment: the fish and wildlife researcher, the Johnston Atoll resident, the eco-tourist, and the homesteader. Dr. Higley described the future users as follows:

- *Fish and Wildlife Worker:* The fish and wildlife worker would reside on Johnston Atoll for ten years. This hypothetical worker would hike, bird watch, dig test pits to examine burrows, and sample vegetation in the radiation control area. The exposure pathways would include inhalation, inadvertent ingestion, and external radiation.

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- *Johnston Atoll Resident:* The resident, probably a military employee, would reside on the island for ten years and work in the radiological control area. The resident's exposure routes would include inhalation, inadvertent ingestion, external radiation, and limited food consumption from patio gardens (potted plants). The soil ingestion pathway did not include root uptakes, foliar deposition, or lettuce and strawberries, since these exposure routes were considered unlikely.
- *Eco-Tourist:* The eco-tourist would reside on the island for two weeks a year and return in five years. The eco-tourist would spend time bird watching on the reserve, which includes non-radiological areas. The primary exposure pathways for the eco-tourist would be inhalation, inadvertent ingestion, and external radiation.
- *Homesteader:* The homesteader is a hypothetical resident of the site that would move in after site abandonment. This future user would reside on the island for 70 years and live year round in the radiological control area. Since the homesteader would grow plants, ingestion would be the primary exposure pathway. Inhalation and external radiation would also be pathways.

Dr. Higley next explained how the RESRAD computer model was applied to the Johnston Atoll risk assessment. For each scenario, the estimated maximum total excess lifetime risk from exposure to radionuclides at 1 pCi/g soil concentration was evaluated. The homesteader displayed the greatest cancer risk. Dr. Higley then showed a graphic illustration of the sources of that risk for each future user in percentages. The eco-tourist would receive the greatest exposure from the external exposure. The fish and wildlife worker, resident, and homesteader would receive the greatest exposure from ingestion. However, among the three scenarios, the significant ingestion pathways differed by soil, plant, or meat ingestion.

RESRAD was then used to calculate dose, as follows:

Eco-Tourist	=	0.01 mrem/y per 1 pCi/g
Resident	=	0.3 mrem/y per 1 pCi/g
Fish & Wildlife	=	0.3 mrem/y per 1 pCi/g
Homesteader	=	0.5 mrem/y per 1 pCi/g

Finally, the risk assessment concluded that the homesteader had the greatest risk and that the exposure pathways differed for each scenario.

Discussion of the Presentations

Discussion between the expert panel and the Working Group:

- Question: What dose conversion factors did Oregon State University (OSU) use for the Johnston Atoll risk assessment (i.e. ICRP 30 or 60)? Response: ICRP 30
- Question: What solubility class did OSU assume for dose conversion factors for plutonium? Response: OSU assumed the plutonium was an oxide, based on the way the plutonium was released through the detonation.
- Comment: Rocky Flats plans to use RESRAD "off the shelf." The Working Group plans to apply the RAC approach using RESRAD 6.0 for comparison. Response: The participants of this workshop should discuss the value of applying a model "off the

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shelf." The best model should be selected and then modified so that the best science can be incorporated. One example of the difficulty the Working Group will have trying to reproduce RAC's work using the model "off the shelf," is the application of the fire. Outside of the fire, the results will be similar.

Open question and comment period:

- Comment: Research needs to be done on mass loading and air resuspension. Response: These are critical parameters and need additional research, particularly the effects of a major fire. The average wind speed across the site is not a difficult determination. That number is sound. Mass loading will be addressed by the wind tunnel research. Other data will also be considered.
- Question: At Rocky Flats and Johnston Atoll it appears the area of contamination is limited. How does RESRAD deal with the geographic limitation? After cleanup what are you really left with? In the practical world, the area that might impact future users would be the area not cleaned up. Response: RESRAD does allow you to consider the physical size, called "area factor." The area factor and the average annual wind speed did not impact the RAC calculation.
- Comment: RESRAD 6.0 should be modified to consider fires since it is an issue at all DOE sites. Response: RAC did not modify code. They came up with a number outside the code and plugged it in.
- Question: How does RESRAD consider temporal short-term events? Response: Acute effect is not an issue for residual contamination, even with fires.
- Question: What is the difference between resuspension and mass loading? Response: Resuspension is the amount of contaminant that is suspended in the air from something in the air that has been previously deposited. Mass loading is a way of getting at that value. Mass loading is the soil concentration in air. If you take that soil concentration in air and multiple it by soil concentration and assume that proportionality, then you will come up with an air concentration.
- Question: It appears the working group is using mass loading and RAC used resuspension. How do the two approaches differ? Response: Resuspension is also used to describe the process of how material gets into the air from soil or other sources. Mass loading, as used by RESRAD, is the air concentration of dust. Implicit in that input parameter is the assumption that there is an amount of radionuclide in that source area. The wind tunnel experiments provide site-specific resuspension data.

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PART 2: Application of Models for Use at Rocky Flats

The second part of the workshop began with a demonstration of the RESRAD 6.0 model, followed by three presentations applying that model. Those presentations discussed how RESRAD 6.0 specifically fits into conditions at Rocky Flats. Following the presentations, time was set aside to discuss what had been presented. Finally, the group reviewed the key modeling issues of concern that were identified throughout the day, checked to see if there were other issues to be added to the list, and identified which issues they would like to focus on in Part 3.

Demonstration of the RESRAD 6.0 Model: Charley Yu, Argonne National Laboratory

Dr. Yu presented a demonstration of the RESRAD 6.0 computer modeling software, and discussed briefly the deterministic code. However, he focused primarily on the probabilistic code, which allows the input of parameter distributions. Software features include the capacity to change concentrations within a time period; calculate risk over a specific time period; determine individual pathway peaks for a specific dose; time-integrated probabilistic risk; input based on specific radionuclide concentrations or daughter nuclides; performing uncertainty analyses; and input of data based on differing soil types. The software has default values that Argonne built in when developing RESRAD. Those values are easily changed based on site-specific needs. Dr. Yu demonstrated on screen how to move through the program software screens, input individual values and parameters, and read the results produced by the software. He stated that RESRAD has a powerful output analysis capability and can produce a great deal of information in both graphic and text format.

Presentation 1: *Consideration of Specific Environmental Conditions, Exposure Pathways, and Uncertainties at Rocky Flats*: John Till, Risk Assessment Corporation

In the morning session, Part 1, Dr. Till presented background information on RAC's independent review of the soil action levels at Rocky Flats. He continued the discussion with this presentation on the specific environmental conditions, exposure pathways, and uncertainty analysis his team applied during their study. Dr. Till first stated that the original scenarios used in the calculation by DOE, EPA, and CDPHE used numbers for a resident that were not significantly different from the numbers used by RAC for a resident rancher. For the inhalation calculation, the resident rancher was placed on the east side of the 903 Pad area, where the highest dose most likely would occur. The calculations were normalized to Pu-239 and Pu-240. Although there is not a uniform distribution across the site, it is probably representative. RAC took into account both the probability and the impact of a fire. An analysis of the pathways involved in the soil action level developed by RAC (35 pCi/g) for scenario 1 (a resident rancher) showed that food ingestion contributed about 11% to the overall dose, soil ingestion contributed about 13%, external exposure was less than 1%, and inhalation contributed around 76% of the dose. RAC's scenario 2, for a 10-year-old child of a rancher, doesn't change the soil action level significantly. However, at 80 pCi/g, the contribution of dose from the different pathways to the child shows that plant and soil ingestion doses increased, and inhalation exposure is dramatically less. RAC's scenario 3, for an infant, was not much different than the

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scenario for a child. Dr. Till concluded by restating that the 35 pCi/g soil action level that RAC derived based on the methodology used was agreed to by the Oversight Panel during the independent study.

<u>Presentation 2: *How RAC Addressed Environmental Conditions at Rocky Flats in Determining Soil Action Levels*</u>: Art Rood, Risk Assessment Corporation

Mr. Rood explained that the first step in modeling a site is to consider the specific characteristics of the site that govern behavior of contaminant movement in the environment, such as geological and meteorological contamination conditions, then evaluate the data available. This dictates what kind of model can be justified. The next step is to construct a conceptual site model of contaminant transport in the environment. Then, the conceptual site model is translated into a mathematical model. The last step is the selection of a computer code. A computer code should not be selected as a first step, with the expectation that it can be forced to work within a particular site. RAC used RESRAD 5.82 and controlled it by a Perl script, a scripting language that can be used to control the inputs and outputs to RESRAD. RAC performed a Monte Carlo simulation, although the Monte Carlo version of RESRAD was not available at the time this work was done. Air concentrations were calculated external to RESRAD, and the probability of a wildfire was considered. The model output was the probability of exceeding the dose limit for a given plutonium soil concentration. Mr. Rood briefly discussed the flowchart steps RAC used to process its calculations through the RESRAD software.

The major difference in modeling was RAC's treatment of the air concentration versus soil concentrations. RESRAD assumes a uniformly contaminated site, which is not the case at Rocky Flats. The model was calibrated to plutonium-in-air measurements at 34 air monitoring stations surround the site. Also used in the model was a wind-speed dependent resuspension model, and meteorological data taken at the site. A separate model was used to compute the probability of a fire. That model estimated the size and location of a fire onsite. The fire had the net effect of increasing the amount of resuspension proportional to the burn area of the fire. Dose conversion factors used were those derived in ICRP 67 (ingestion) and ICRP 71 (inhalation). RAC felt that a soil action level would not work very well if exposure occurred from contamination not located where the receptor is situated. A situation like this would occur in an inhalation pathway where plutonium is transported in air from areas of high contamination to locations of low contamination, where the receptor may be residing. So instead of calculating an RSAL, RAC proposed that a remediation strategy be developed which considers the current contamination levels at the site and estimates the dose at all potential receptor locations. If the dose exceeds the dose limit at selected receptor locations, then you simulate a remediation. This process is then repeated until the dose limit is achieved at all locations onsite.

<u>Presentation 3: *Application of the RESRAD 6.0 Model to the Specific Conditions and Exposure Pathways at Rocky Flats*</u>: Bob Nininger, Rocky Flats RSAL Working Group

Dr. Nininger discussed how the RSAL Working Group considered modeling considerations through RESRAD 6.0. He stated that the significant questions are more about putting the

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parameters together and placing the parameters into the model itself, such as representative scenarios, appropriate parameters and conditions, and representative model results representing the range of exposures that might exist. The exposure scenarios being looked at by the Working Group are a wildlife refuge worker, an open space worker, an office worker, and a rural resident. Those scenarios suggest that the following contaminant pathways be modeled: soil ingestion, plant ingestion, external radiation, inhalation, and water. The inhalation pathway requires a careful definition of scenarios, and the water pathway requires a greater understanding of the chemistry involved. It is important to consider "sensitive" pathways such as the root depth of plants, contaminant depth, wind speed, anticipated air concentrations, and exposure factors like the time spent indoors and inhalation rates. More time is spent reviewing and looking at the sensitive pathways by assigned point values. For instance, if a parameter is narrowly defined, it will receive a singular point value. For parameters that are sensitive where the input change makes a big difference in the dose output, the distributions are reviewed more closely. Dr. Nininger explained a couple of case studies reviewed by the Working Group, one being the assignment of distribution functions, and the second being air mass loading. The Working Group is having difficulties coming up with a good representation of a mass loading that takes into account factors other than normal operating conditions. Less common events, such as a fire, are important to consider. However, a probabilistic approach to the fire scenario is difficult to determine.

Baseline mass loading includes impacts from large construction projects, vehicle traffic, deer herds, and impacts from area growth. Onsite meteorological data span more than 35 years, and include precipitation and wind data. To set the baseline for coming up with a mass loading factor, site and statewide data is used, as well as precipitation factors, Front Range fire data, and wind tunnel data. The resulting mass loading is a statistical distribution, which then can be input to RESRAD. There are many challenges associated with the parameters such as whether the parameters are in sync with the requirements of RESRAD. For instance, an "indoor time fraction" is not the fraction of time spent indoors onsite while working, but the fraction of time spent indoors onsite on a 24-hour basis. Also, more unrealistically, "mass loading" as it represents an area source must consider a disturbance as distributed over the entire field of influence, rather than just the contaminated area. Thus, RESRAD will scale that mass loading by the area factor, which comes from the area that is really disturbed by the fire or other identified disturbance. Dr. Nininger noted that he has more information on sensitivity analysis that can be presented at this workshop.

<u>Discussion of the Presentations</u>

Discussion between the expert panel and the Working Group:

- <u>Question (John Till)</u>: Explain how you will use RESRAD with the fire scenario. <u>Response (Bob Nininger)</u>: Small fires onsite are not uncommon; the assumption is that it may be once per year. The probability of a fire in a contaminated area presents more of a difficulty. There is an area of approximately 300 acres that encompasses all contamination above 10 pCi/g. The probability of a fire occurring within that 300 acres within the 6,500 acres of the site is a matter of a simple ratio. There is roughly a 5% probability of a fire occurring in the 300-acre contaminated area. Using resuspension measured in the wind tunnel, it is possible to derive mass loading multipliers for a spring

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fire and a fall fire. Data is also available for the probability of a fire occurring in either the spring or fall. From that information, a hypothetical mass loading distribution can be generated.

- Question (Kathleen Meyer): You said that distributions would be developed for some exposure parameters with high variability. Could you provide examples of some of those? Response: They are primarily the ones listed in the handout. [Refer to Attachment I at the back of this summary] The sensitivity of parameters is pathway-specific and isotope-specific. Parameters are ranked in order by sensitivity coefficient, which is the change in dose relative to the change in a parameter over a given range.
- Question (Charley Yu): What parameters were assigned probability distributions in the RAC Study? Response (Art Rood): A limited set was reviewed. Uncertainty was not considered in the exposure scenario, such as the person's behavior or physical attributes. That may be in conflict with the approach of the regulatory agencies. For the purpose of the RAC Study, uncertainty refers to the precision with which we can estimate the concentration of contaminants in environmental media. This is measurable. Behavioral attributes are not measurable because the receptor is only a hypothetical individual. RAC came to the conclusion that mixing the two tends to confuse what the uncertainty associated with an output distribution really represents. In RAC's case, we know exactly what it represents: our ability to measure contaminants in the environment. When you combine this with the behavior of a hypothetical individual, I'm not sure what the uncertainty estimate really represents. The only parameters considered for probabilistic treatment in the analysis were air concentration, soil concentration, root uptake factors, K_d, and all other parameters that govern transport.
- Question (Jim Benetti): When you located a receptor east of the 903 Pad, was that the point of maximum exposure? Response (Art Rood): Yes, the most conservative value was for a receptor located a little farther east of the 903 Pad. Soil action level is sensitive to the soil concentration to dose ratio. The soil concentration at that location is very low, but the dose is not proportionally low. Consequently, the soil concentration to dose ratio is maximized there. The area was chosen based on numerous simulations, and some intuition.
- Question (Charlie Yu): How do you determine the length of time of the fire? Response (Art Rood): The larger the burn area, the longer the fire's duration was considered to be. The duration of the fire was assumed to be relatively small relative to one year, so we did not look at the actual release during a fire.
- Question (Bob Nininger): Did you consider the episodic nature of resuspension? Response (Art Rood): Yes, we accounted for fluctuations in wind speed. We calibrated our air model using five years of wind speed and air sampler data for the site. Basically, it is an empirical model incorporating many complex processes that are not well-characterized. The real benefit of an empirical model is that it simplifies these complex processes.
- Question (Jeremy Karpatkin; Jim Benetti): What was RAC's modification to RESRAD, if any, to enable the program to do something different with air resuspension? I understand that RESRAD accepts slightly different input parameters than those used in RAC's empirical model. How did you get them into a form that RESRAD accepts? Response (Art Rood): RAC did not modify RESRAD. The RESRAD 5.82 code remained intact, unmodified, and was used in the executable version that was received

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from Argonne. We did obtain the source code to see how to get at the input files and operated on the command line rather than Windows. RAC did work with the input so RESRAD would calculate the concentrations RAC wanted. Basically, we back calculated a mass loading factor to get the desired air concentration.

- Question (Charley Yu): If I understand it correctly, RAC's empirical air model correlates known soil contamination at Rocky Flats with a mass loading factor for input to the RESRAD code. If there were more contamination present in the soil than has previously been identified, what effect would this have on RAC's calculations? Response: RAC used every piece of data available to extract the correlation between concentration in soil and air. If additional data is now available, it could be performed again.

Open question and comment period:

- Comment: Changes in ICRP regarding the dose conversion factors play a large part in the difference in cleanup strategies and decisions at different sites. Response (Kathryn Higley): Yes, you're right. These factors may change by a factor of 10 or more, and this definitely affects the cleanup level. Another issue is what standard should be used to back out an unacceptable soil level – a dose standard or a risk standard? The choice of standard may change acceptable soil contamination level by a factor of 2 or more. Second Response (John Till): That is exactly what I meant earlier by the term, robustness of the RSAL. How do we make a decision today that is going to endure? Scientists are accustomed to plugging in a single number for dose conversion factors, even though we all recognize that these factors are uncertain. This is an area where science needs to focus attention in the future. For now, I don't know the best way to solve this dilemma. One solution might be to use the most conservative factor for each pathway that has been published over the years. That would be one way to take this uncertainty into account.
- Question: Groundwater is not being considered as a pathway in the scenarios currently being considered. What needs to be done in RESRAD to address the consideration of groundwater as a pathway? Response (John Till): RAC recognized the potential importance of groundwater as a pathway, but it was beyond the scope of RAC's work to consider it. The way RAC took groundwater into account, it did not make much impact on the soil action level. RESRAD cannot handle surface water or groundwater as it should be handled. Groundwater needs to be considered very thoroughly outside of the soil action levels.
- Comment: The probability of a fire is not so difficult to determine. A one in a thousand expectation for a fire assumed by RAC seems out of line. It is reasonable to assume at least one intense fire and many low-grade fires within the lifetime of the receptor. Response (John Till): The issue of the probability of fire bothered me even as we were doing the study. By the time we decided to model the fire, we had only 2 months left in which to complete the work. That doesn't mean it isn't done right. We simply didn't have all of the data necessary to come up with a reasonable probability for the fire. In terms of complying with an annual dose limit, I believe you have to assume the probability of fire equals one.

What are the Key Modeling Issues of Concern Related to Rocky Flats?

At the end of Part 2, members of the expert panel, the Working Group members, and all workshop attendees worked together to identify the key modeling issues of concern related to Rocky Flats. This was done in order to prioritize issues that would be discussed the next day in Part 3 of the workshop. In the initial round of discussions, the group as a whole identified the following issues

Sensitivity analysis	Discussion of RAC's soil action level
Risk assessment using RAGS method	Comparison of model performance
Wind tunnel	Sensitive parameter values
Uncertainty in scenario parameters	Risk versus dose
Uncertainty in dose conversion factors	Differential sensitivity to radiation
Uncertainty in breathing rates	Scenario validation
Comparison of key parameters	Non-linearity in calculations

First, some related issues were grouped together. Next, the facilitator led the group in a voting session to prioritize the top issues that would lay the foundation for Part 3, *Key Modeling Issues of Concern at Rocky Flats*. Each individual present was given a total of three "votes" to cast for their top issues. Four topics received the most votes from the group. Individuals on the expert panel and with the RSAL Working Group were asked to either give a presentation the next day or to come prepared to discuss the following four issues:

- Risk versus dose. Is one method for deriving soil cleanup levels preferable, from a scientific standpoint, than the other? What are the relative uncertainties between the two methods? How is risk calculated according to EPA's *Risk Assessment Guidance for Superfund* (RAGS)? How does the RESRAD program handle calculation of risk?
- Uncertainty. How do scientists account for uncertainty as related to scenario parameters (particularly breathing rate) and dose conversion factors? Why is it important to distinguish between uncertainty and natural variability? What implications does cumulative uncertainty have for calculation of the RSALs?
- Sensitive parameters. How is sensitivity analysis performed in order to identify sensitive parameters? What approach is being followed by the Working Group to choose values or distributions for sensitive parameters, and the mass loading parameter in particular? To what extent will the wind tunnel studies conducted at Rocky Flats shed light on the mass loading parameter?
- Comparison between RESRAD 6.0 and RAC's work.

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Part 3: Key Modeling Issues of Concern at Rocky Flats

Part 3 focused on key issues deemed important by vote of the group. As envisioned by the workshop planning committee, this was really the heart of the workshop. On each of the key issues, the Working Group shared its approach with the group, and invited comments and criticisms from the panel of experts. Afterward, the general audience was allowed to ask questions. The issues given high priority were as follows:

- Risk versus dose
- Uncertainties
- Sensitive parameters
- Comparing the RESRAD 6.0 model to RAC's work

Issue1: Risk versus Dose

Presentation: *Risk Assessment Using RAGS (Risk Assessment Guidance for Superfund) Methodology*: Susan Griffin, EPA

Dr. Susan Griffin, toxicologist with EPA Region VIII, gave a presentation entitled "Development of Risk-Based Soil Action Levels at Rocky Flats." Just as the RESRAD model has an extensive pedigree, EPA has employed the same risk-assessment framework for over a decade. Originally developed in 1983 by the National Academy of Sciences, EPA adopted RAGS methodology as policy six years later. Under this approach, a site conceptual model is developed to describe the pathways by which human beings may reasonably be expected to come in contact with environmental contaminants. Pathways are categorized as being significant, insignificant or incomplete. This is where the risk assessor relies on stakeholder input in order to understand current and future uses of the site. For each pathway identified in the site conceptual model, there is a standard RAGS equation, simple enough to be performed using a spreadsheet. The intent is to make the underlying assumptions transparent, and the overall approach consistent from site to site. That is not to say, one size fits all; site-specific values should be plugged into the risk equations whenever possible.

When RAGS methodology is used to derive soil action levels, the end result is a quantitative estimate of the lifetime cancer risk attributable to various levels of contamination in the environment. Deciding what level of risk to future users will be deemed acceptable is ultimately the role of the risk manager, not the risk assessor. EPA guidance says that cleanup action is generally not warranted unless the cumulative cancer risk from all carcinogens is greater than one in 10,000 (10^{-4}).

Presentation: *Risk vs. Dose as it relates to RESRAD*: Charley Yu, Argonne

Dr. Charley Yu demonstrated some features of RESRAD that pertain to calculating risk. The dose conversion factor library within RESRAD can be changed by inputting risk factor values. The risk report generated after a RESRAD run correlates intake quantities of radionuclides to

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an estimation of risk. The desired output is available by pathway and in total. According to Dr. Yu, the RESRAD code calculates risk in a manner consistent with EPA RAGS methodology.

Discussion of the Presentations

Discussion between the expert panel and the Working Group:

- Question: How do you determine the significance of a pathway? Response: An insignificant pathway is one in which the exposure is so small that it is overshadowed by other pathways. This determination can be made through back-of-the-envelope screening calculations, combined with professional judgment. If a particular pathway is incomplete for a given scenario, then the lifestyle of the receptor associated with that scenario is such that no route of exposure exists.
- Question: In RESRAD, can dose conversion factors and risk factors be entered as probability distributions? Response: Yes, they can.
- Question: How do the screening-level calculations consider environmental transport and ingrowth of radionuclides? Response: The basic RAGS equations do not account for either. In the case of RFETS, this is not deemed to be a problem since the highest exposures are believed to occur at Year Zero.
- Question: What about interactions or synergies between contaminants? Presenter's Response: We do not know enough about these complex processes, so risks from different contaminants are assumed to be additive. This is believed to be a conservative assumption.
- Question: How does the Working Group take stakeholder input and independence into account? Response: The objective of the Working Group is to generate scientifically defensible RSALs. Stakeholders are allowed to attend Working Group meetings and have real-time input to the process.

Open question and comment period:

- Question: When selecting exposure scenarios, what timeframe must the risk assessment contemplate? Response: There is no definite time period for the risk assessment. EPA risk assessment involves analyzing exposures that can be reasonably anticipated. At some point on the horizon, projecting into the future becomes unreasonable, but it is impossible to say exactly where the cut-off lies.
- Panelist Comment: The choice of scenarios is crucial to the science. Selecting a scenario that will protect the public into the foreseeable future is the most fundamental starting point for technical calculations.
- Question: We all know that the RSAL is for surface soil, but erosion will eventually cause subsurface soil to become surface soil. How does EPA differentiate between the two? Response: The risk assessor looks at the means by which future receptors may come in direct contact with contaminants. Therefore, below-ground contamination is an incomplete pathway with respect to inhalation and soil ingestion. Insofar as groundwater is determined to be a viable pathway for scenarios being developed by the RSAL Working Group, subsurface contamination will have to be examined.

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- Question: The only adverse effect that has been mentioned is cancer. What about non-lethal effects and toxicity? Response: Radiation standards do take into account non-fatal cancers and genetic effects.

Issue 2: Uncertainty

Presentation: *Scenario Parameters*: John Till and Kathleen Meyer, RAC

Dr. John Till discussed parameter uncertainty in terms of the RAC study of soil action levels for Rocky Flats. It bears mentioning that scientific opinion is divided on this issue. Even among members of the RAC team, there was some debate on the proper way to handle uncertainty versus variability. In the end, the group agreed to make a clear distinction between environmental transport parameters and scenario parameters.

Environmental transport parameters pertain to complex processes (e.g., plutonium uptake by plants) that are not clearly understood. Whenever possible, RAC developed probability distributions to estimate this uncertainty. Conversely, RAC decided not to treat scenario parameters – lifestyle attributes of the receptor – as uncertain, the rationale being that the characteristics of the hypothetical receptor are known. Scenario parameters are variable rather than uncertain. Take breathing rate, for instance. We know the receptor breathes; we just don't know how much. For scenario parameters, Dr. Till believes it is preferable to assign point values rather than distributions. To come up with a point estimate, one needs to consider the entire range of possible values.

Next, Dr. Kathleen Meyer talked about how point values for breathing rate and soil ingestion were derived. Data from various breathing rate studies were aggregated according to activity level (sedentary versus active), resulting in a probability distribution. Having captured the broad range of human variability, RAC investigators felt comfortable in choosing the 95th percentile value from that distribution. Whereas breathing rate can be quantified with a high degree of accuracy, soil ingestion is quite difficult to measure. Further difficulty may be encountered in attempting to separate intentional from inadvertent soil ingestion. Here, as with breathing rate, a distribution was created using data from a number of studies. In this case, however, RAC selected the 50th percentile value because they felt there was a lot of conservatism built into the soil ingestion studies, all of which were conducted over short periods of time during a warm season when people are more likely to be outdoors. The ingestion rates observed during this snapshot in time may not be representative of the amount of soil ingested over the course of a year.

The foregoing is not to suggest which parameters call for central tendency as opposed to high-end values. Rather, RAC's work suggests a standard methodology that can be used in selecting deterministic parameters. Above all, RAC's mindset in describing scenarios was to view them as a benchmark against which to measure the protection of human health; hence, their rationale for assigning upper bound values to some parameters. Had they chosen distributions for all scenario parameters, the RSAL would have been generated by sampling from the high and low ends of the distributions – an approach that is ultimately less conservative and less protective.

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Discussion of the Presentations

Discussion between the expert panel and the Working Group:

- Question: Is it equally valid to perform the calculation using distributions for scenario parameters? Response: A deterministic approach is not necessarily preferable to a probabilistic approach. The important thing is that the risk assessor be consistent, using either all distributions or all point values for the scenario parameters. Other Panelist Response: If the decision is made to use a probabilistic approach for scenario parameters in addition to environmental transport parameters, what is variable must be kept separate from what is uncertain. To do so is certainly possible, but one must understand that it is also computationally intensive.
- Comment: One of the more important issues in risk assessment is how to account for uncertainty in dose conversion factors, but the ICRP (International Commission for Radiation Protection) does not want to address it. Helen Grogan has just completed a groundbreaking study on uncertainty in risk coefficients, which will appear in the May issue of *Health Physics*. Hopefully, this will prompt similar work on dose conversion factors.

Open question and comment period:

- Question: Which risk model is better, the ICRP model in which dose is converted to risk by multiplying by a factor, or the EPA biokinetic model in which risk is estimated more directly? Response: The ICRP model is simpler. We have a lot of information about the relative doses to the different organs from a given radionuclide intake. Using the dose conversion factors, one can work out quite well what is the total dose from a given exposure. Coming from a separate angle, the EPA model is more sophisticated, but our knowledge of how radionuclides move through the body is still rudimentary. As more data is collected, the EPA model should yield a better estimate of population risk, but for the moment, we are in a time of transition where it remains unclear which model gives the best answer.
- Question: What about the relative uncertainty between the two approaches? Response: There is large uncertainty associated with both of them.
- Panelist Comment: The dose methodology used in the past is based on our ability to measure energy deposition in specific tissues and then make an interpretation of the damage done to the body as a whole. From a scientist's perspective, this measurability has a distinct advantage. Biokinetic models are more theoretical at this point, in that they are based on observation of how material is distributed through the body. From such observation, energy deposition can be predicted, and then correlated with risk. I don't think a strictly biokinetic model is ever going to provide all of the answers, because there is still the issue of external radiation to deal with.
- Comment: Realism should be the goal of the risk assessor. The decision to add conservatism lies with the risk manager. Therefore, it would seem inappropriate to choose a 95th percentile value for breathing rate, for example. Response: Scientifically speaking, RAC probably could have selected a somewhat lower deterministic value for breathing rate. However, the 95th percentile value was selected for breathing rate in the interest of involving the public. We felt using a high-end, as opposed to a mean, value made little difference to the final result, so as scientists we were able to live with that.

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- Comment: The ICRP dose conversion factors assume plutonium has a relative biological effectiveness (RBE) of 20. That average value is not protective of the more vulnerable members of the population. Some researchers have suggested assigning a much higher RBE to plutonium. Therefore, it could be argued that the ICRP averaging approach on which radiation standards are based is not particularly conservative.
- Panelist Comment: Over the last couple of days, I've gotten the impression that some experts are reluctant to fit distributions to biological data, such as breathing rate. EPA has much experience with fitting distributions to biological variables. The agency has published guidance on doing so. Response: That is fine, as long as biological variability is distinguished from uncertainty in the transport model.
- Question: What are the RSAL Working Group's annualized values for breathing rate and soil ingestion? Response: The group plans to use a distribution for both of these parameters. Therefore, it is difficult to make a direct comparison between RAC's point values and the distributions currently being developed.
- Question: With the tremendous uncertainty in dose conversion factors, how can the public have confidence in them? Response: As a scientist, I struggle with this myself. RAC's approach was simply to use the latest dose conversion factors because they are the most scientifically defensible. I will say, though, they are unlikely to change dramatically in the near term. It is good for members of the public to appreciate the complexity of this and to appreciate what we really don't know. That's why, whenever we make a decision about soil action level, uncertainty needs to be taken into account.

  On the surface, some of the choices RAC made could be perceived as ultra-conservative, but in fact, we were trying to make choices that would last. This is what we mean when we speak of the robustness of the RSAL.

- Comment: The biological effects of radiation vary from one organ to another and from one radionuclide to another. Yet, dose conversion factors approved for regulatory purposes ignore this, and are derived on the simplified assumption that all internal emitters (e.g., plutonium) have the same effect on the body. If the dose conversion factors were adjusted to account for these differences, the RSAL could change by an order of magnitude. Response: One of the things we did in our study of the risk factors for plutonium was to not just take the generic RBE of 20 for plutonium, but rather to look at it on an organ-specific basis, and indeed the data for plutonium do support using different mean values than 20 for the different organs of interest. In fact, we came up with probability distributions for that.

Issue 3: Sensitive Parameters

Presentation: *Parameter Sensitivity Analysis:* Bob Nininger, Kaiser-Hill

Dr. Robert Nininger of Kaiser-Hill explained how the RSAL Working Group analyzed the relative sensitivities of more than a hundred model parameters. The analysis involves varying parameters one at a time over a certain range and observing the resultant change in dose. Sensitive parameters are those of greatest importance in determining the RSAL. The purpose of sensitivity analysis is to identify which parameters deserve the most intensive focus when it comes to selecting parameter values. Some sensitive parameters may be assigned probability distributions, depending on the quality and quantity of data available.

One of the challenges in conducting sensitivity analysis is that there is no absolute standard for determining sensitivity. Parameter sensitivity must be judged relative to other parameters within a given pathway. The majority of parameters had little influence on the outcome. Overall, fifteen to twenty parameters registered some sensitivity, indicating the need for intensive scrutiny by the Working Group.

<u>Presentation: *Wind Tunnel Studies*:</u> Bob Nininger, Kaiser-Hill

Dr. Nininger then presented the results of wind tunnel studies at Rocky Flats. The studies were conducted to determine the increase in mass loading that occurs in the aftermath of a grass fire. A portable wind tunnel was used to generate high winds and collect resuspended soil particles for subsequent analysis. The data indicated a twelve-fold increase in erosional potential immediately following the fire. Two and a half months later, the burned area still exhibited greater emissions than the unburned area, although the increase was no longer as pronounced. The data also showed that, at a certain wind speed, there is a limited reservoir of material available for resuspension. Given sufficient time for natural weathering to occur, that reservoir will be replenished.

The RSAL Working Group believes that the wind tunnel data can be correlated with the site meteorological database in order to build an empirical distribution for mass loading. In doing so, the seasonality of the fire would be crucial. A spring fire is assumed to have a lesser impact on resuspension than a fall fire, owing to the fact that revegetation following a spring fire would likely be rapid. After a fall fire, the ground could remain denuded for six months or more.

<u>Discussion of the Presentations</u>

Discussion between the expert panel and the Working Group:

- <u>Comment</u>: The wind tunnel studies are good, but it seems to me we should pursue the same experiment in the natural environment without the wind tunnel, just looking at a burned area. It wouldn't even have to be at RFETS. You could take any area of similar ecosystem where a burn had occurred, and do a pre-burn and post burn analysis. <u>Response</u>: That would be a different measurement, and the results would be confounded by all the natural effects that are taking place at the time of the measurement.
- <u>Follow-on Comment</u>: But that's precisely the answer you want. <u>Response</u>: It is the answer we want, but the uncertainty associated with the answer will be higher because of those confounding effects.
- <u>Comment</u>: One good source of information might be the rash of fires at DOE sites last summer. In response to the outbreak of fires, DOE stepped up their monitoring, so the Working Group might be able to get something applicable to the modeling at Rocky Flats from that.
- <u>Comment</u>: I wonder if the wind tunnel is really an adequate representation of reality. To be sure, it captures horizontal wind movement. However, I remember from some

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of the work I did a long time ago on Rocky Flats that it is not the horizontal wind that gets the particulates up into the air, but the vertical pounding. With thunderstorms and the like come turbulence and vertical wind currents that flex the residual vegetation, lift material up and disturb the soil. That's what can be responsible for a fair amount of the resuspension. Response: That's right. There is turbulence that is not taken into account with the wind tunnel and we still need to look at that factor. Another factor in the environment that bears further study is resuspension due to the vegetation itself. We believe material is being splashed onto leafy surfaces by rainfall, and then, as the leaf dries and flexes in the wind, we get resuspension from the leafy matter. This is one of the chronic resuspension factors that we see at the site.

- Comment: This presentation has stimulated a lot of good thought, and I was just thinking of the dose reconstruction studies at Rocky Flats, part of which had to do with investigations of resuspension from the 903 Pad area. Granted, the monitoring data was somewhat crude and not without its problems, but it presents an interesting opportunity for comparison. When they removed the barrels from the pad and burned the weeds off the surrounding area, we saw a huge increase in air concentrations at the S8 Sampler. We could correlate that with wind speeds measured at the time. We are very fortunate that NCAR was doing a special study then and had set up a number of meteorological stations in the area to measure both wind speed and direction. We could use that data to basically calibrate our model. Since they burned the vegetation, the data gives some idea of the relative increase in resuspension after a fire. And the increase was substantial. The S8 concentration before the fire as compared to that seen afterward may provide some additional data to help look at this problem on a larger scale. The wind tunnel studies are interesting and worthwhile, but there is a scale problem with them. I also agree with the previous comment that failure to capture turbulence is a potential drawback. Response: The one important factor that needs to be accounted for with the data from the 903 Pad is soil disturbance. In contaminated areas, even the slightest soil disturbance can be detected in samplers, potentially confounding the results.

Open question and comment period:

- Question: With the unidirectional airflow inside the wind tunnel, I would imagine some of the material is being dammed, or held back, by grass or other barriers. How are you taking account of that? Response: That particular factor is not taken into account with the wind tunnel. However, the turbulence question would take that into account, and that's part of what we're investigating.
- Question: Most of the wind tunnel data was collected in the wettest months of the year, which would seem to skew the results. How are you taking into account the time of year? Response: Yes, the wind tunnel is a snapshot in time. In terms of whether the study was conducted during a wet period or not, the site received less-than-seasonal amounts of rainfall in the spring of 2000. Most of the precipitation came later in the year, in the July and August time frame, so the wind tunnel data is not representative of typical spring conditions at the site, so much as of a period in time with less-than-normal rainfall.

- Comment: It would be really valuable if this wind tunnel study were subject to peer review. Response: We do want to have the work peer-reviewed, so that we can better understand its inherent limitations.
- Comment: The wind tunnel study should be peer-reviewed by scientists who are not involved in DOE work.

Issue 4: Comparing RESRAD 6.0 to RAC's Work

Presentation: *Comparison Between RESRAD 6.0 and the RAC Study*: Jim Benetti, EPA

Jim Benetti presented the results of a comparison he made between RESRAD 6.0 and the RAC Study. To facilitate the comparison, he ran RESRAD 6.0 deterministically using similar input parameters to those used in the RAC Study. Direct comparison was impossible because he didn't have access to the mass loading inputs selected as part of RAC's Monte Carlo fire simulation. In lieu of them, he started with a baseline mass loading of 26 micrograms per cubic meter, the figure used in the 1996 RSAL calculation, and varied the baseline up to a factor of 200. This is the multiplier RAC assumed in the worst-case fire scenario. Interestingly, at that upper end multiplier of 200, the RSAL calculated with RESRAD 6.0 was 23 pCi/g, roughly a third lower than the 35 pCi/g RSAL calculated by RAC. This suggests that RESRAD 6.0 unmodified may actually be more conservative than RESRAD 5.82 as modified by RAC. It also suggests that the real differences between the work the RSAL Working Group is doing currently and RAC's work from a year ago have nothing to do with the model itself, but rather with the choice of input parameters.

Discussion of the Presentation

Discussion between the expert panel and the Working Group:

- Comment (Art Rood): RAC did not use a single value for mass loading, but a distribution. That complicates matters. Nonetheless, the results of your comparison are striking. It is also important to note that the mass-loading multiplier is not the only important aspect of the fire. There is also the timing of it. Over the course of 1,000 years, the plutonium inventory in the soil will change. Jim's analysis doesn't account for this, and therefore, doesn't quite achieve comparability.
- Question (Mr. Benetti): I'm interested in knowing whether you feel this is a valid way to compare the two approaches. Comment (John Till): In order to check the work that RAC has done, it is not sufficient to use similar parameters. One must replicate RAC's overall methodology.
- Presenter's Comment: Evaluating RAC's work is not the objective of the RSAL Working Group. What we hope to gain from this crude benchmarking is confidence in the Working Group's approach.
- Comment (Art Rood): I think if I sent you all of the mass loading inputs for each Monte Carlo run, you should be able to do the comparison. Since the deterministic part of RESRAD 6.0 is unchanged, I'm not sure what you would prove. Essentially, you would be plugging the same input parameters into the same code.
- Comment: All I'm trying to prove with this benchmarking is that the path we, as a Working Group, have chosen is adequate.

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- Comment (Art Rood): Recognizing the limitations of what you had to work with, I think the comparison is close.
- Comment (Tim Rehder): If in fact we can say that RESRAD 6.0 operates similarly to the way RAC utilized RESRAD 5.82, then the difference lies in how the fire was modeled. In 1996, the Agencies did not model for a fire, and I agree with John Till that this was a mistake. The question was also raised as to the appropriate frequency of a fire. For purposes of complying with an annual dose limit, it seem reasonable to me to assume the probability of fire equals one. However, when calculating a risk-based RSAL over a period of years, the probability of fire becomes crucial because the catastrophic fire would not occur every year. The challenge for the Working Group is to come up with a mass loading distribution. Using site-specific data and the wind tunnel studies as a starting point, it should be possible to derive a hypothetical distribution that will adequately address the increase in mass loading after a fire, taking into account both the probability and the seasonality of a fire. As mentioned during the wind tunnel presentation, a fall fire is likely to have a more severe impact on mass loading than a spring fire.

  The question of how to estimate the probability of a fire is an interesting one. There is historical fire data. However, it may be more prudent to assume one tenth of the site burns every year, consistent with the RFETS Vegetation Management Plan. This would likely be a conservative assumption since no burning in the contaminated area is planned.

- Comment (John Till): The initiative seems correct. Technically-speaking, I'm concerned about how one melds all of this information together into a mass loading distribution, because you have a number of different issues involved, such as the area of the fire and the probability of a fire. If you deal with the dose limit on an annual basis separate from the integrated risk over a 30-year period, it is definitely going to give you a different answer, and possibly be more restrictive, but we don't know for sure yet. How does the Working Group plan to get an empirical mass loading distribution into RESRAD? Response: The details aren't completely worked out yet, but our preliminary approach involves melding various factors into a series of annualized multipliers, each with its own assumed probability of occurrence. For instance, a spring fire would result in a different annualized multiplier than a fall fire, because recovery would occur more quickly after a spring fire.
- Comment (Art Rood): RAC viewed fire as a discrete event occurring over the course of 1,000 years. Conceptualizing fire as continuous burning, as in the sense of a prescribed burning regimen, definitely has some advantages, especially in regard to a model like RESRAD that uses annual average mass loading. The question I would be asking is whether continuous burning is reasonable or whether you should assume some kind of catastrophic fire that produces a bump in mass loading at some discrete year in the future. If the latter is the case, then I don't believe folding the effects of the fire into the mass loading distribution will work. If the assumption is a yearly fire of a constant size, it may be reasonable to do so.
- Comment (Charley Yu): All of the mass loading input into RESRAD is assumed to be a one-micron particle size. Perhaps the mass loading input needs to be lowered to

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account for the fact that in reality not all airborne particles in the PM 10 range can be inhaled.

Open question and comment period:

- Comment: If you assume a catastrophic fire, then you should adjust plant ingestion for the fact that the land is no longer available for food production. The idea of looking at smaller fires of limited area has great merit because, even after DOE has left, local governments will have fire protection that should extend into the site. I would encourage the Working Group to think about that.
- Question: What are the characteristics of the catastrophic fire modeled by RAC? Response (Art Rood): The conditions of the fire were based on 60 to 70 years of fire data from the Roosevelt and Arapahoe National Forests and from the Pawnee National Grasslands. We considered not only the probability of fire occurring within the site boundaries, but also the area of the fire, which is basically synonymous with the magnitude. The effect of the fire on the receptor is dependent on the size of the fire as well as the location of the fire relative to the receptor.

General Open Discussion

With time remaining on the agenda, Facilitator Laura Till opened the floor to additional comments or questions the expert panel, the Working Group members, or the audience participants wished to make.

Discussion between the expert panel and the Working Group:

- Comment (S. Y. Chen, Argonne): The issue of what is the appropriate data for developing a mass loading distribution has not been addressed adequately. The Working Group is not focusing on particles of a one-micron size. It is this fraction alone that would be appropriate for input to RESRAD. Response (Bob Nininger): The data presented this morning was PM 10, which of course is not the same as one-micron particles. To isolate the one-micron component from the overall PM 10 would reduce mass loading by a factor of 20 or 30. Particle-size distribution data taken from east of the 903 Pad with a 5-stage, size-fractionating sampler shows that the radioactivity of soils is roughly proportionate to the mass of the soil.
- Comment (John Till): RAC had a lot of trouble with this as well. That's why we took the approach that we did, to use the atmospheric monitoring data and the soil concentration data.
- Comment (S. Y. Chen): I have a data collection concern. To run RESRAD 6.0, one needs to have the appropriate data. One-micron particle size is the data requirement for RESRAD 6.0.

Open question and comment period:

- Question: Under a fire scenario, the fire occurs on an area of high contamination, presumably the 903 Pad. The person getting the maximum inhalation dose resides downwind of the fire, on an area of relatively low contamination. Is the person ingesting soil from that immediate area, or soil from the highly contaminated area? Response (John Till): My opinion on how it ought to be modeled is as follows. With regard to

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inhalation, the receptor should be placed downwind of the fire. With regard to soil ingestion, the receptor should be placed upwind, where the fire occurred. This may sound like a contradiction, but it is realistic because the person could move around various parts of the site. I believe that what I've described is the prudent modeling decision.

- Panelist Comment: It is important to recognize that the model assumes the receptor is standing in the middle of a circle of contamination. That's the situation RESRAD simulates. So, the model has no way to tell when one puts some other data into it.
- Question: Is Argonne developing an off-site module for RESRAD? Response (Charley Yu): There is a beta version of RESRAD Offsite that we have been distributing for a couple of years, but DOE has not yet formally released it.
- Comment: The data that is being put into RESRAD do not seem to correlate with what the RESRAD developers intended. This problem needs to be explored. Response (Charley Yu): The dose conversion factors published in Federal Guidance Reports are based on one-micron particle size. Please understand that there are other dose conversion factors available, but those are the ones accepted by the federal government. Therefore, the mass loading factor that should be input into RESRAD is the one-micron particle size. Particles much larger than that cannot be inhaled.
- Comment (Kathryn Higley): As Charley said, there are different dose conversion factors for different particle sizes. Bigger particles tend to be screened by the filaments in the human nose. Smaller particles, below one micron and smaller, start behaving as a gas and tend to be exhaled. A common approach in modeling is to assume all respirable particles are one micron. This is considered a conservative assumption and gives a higher estimate of dose than if one were to adjust for those bigger and smaller particles. Particles in the one-micron size range are believed to have the greatest adverse effect on human health.
- Question: Will the RSAL calculation take into account the fact that resuspension could change in the future due to greater occupancy and greater human activity? Response: The Working Group is proposing to use data from a statewide database as a baseline value for mass loading. That data is based on all of the stations monitoring throughout the State of Colorado. The median mass loading statewide is around 20 micrograms per cubic meter. This is believed to be more conservative than using strictly site data because only a limited scope of activity is currently allowed at the site, whereas statewide data encompasses the full range of human activity.
- Comment: If RESRAD can only accept data for mass loading in the one-micron size-range, it is a problem with the model, not the data being used by the Working Group. The assumption, apparently built into RESRAD, that only one-micron particles can be inhaled is one that does not hold up against reality. It seems appropriate to use one-micron dose conversion factors as the best conservative estimate, but not to input only a fraction of the respirable particles that are being resuspended. Response: The Working Group plans to treat all particles PM 10 and below as though they were one-micron particles, as far as dose conversion factors are concerned.
- Question: What is the Working Group doing to account for drought and other phenomena such as dust devils or tornadoes? Response: The Working Group is considering drought, but in our professional judgment, the severe, fall-fire scenario is considered to be the major impact on resuspension. As far as dust devils are

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concerned, ephemeral events account for a negligible fraction of the dose. It is the dust inhaled under average or chronic conditions throughout the course of a year that poses the real danger to public health.

PART 4: Where Do We Go From Here?

The fourth part of the workshop was intended to allow members of the expert panel, the Working Group members, and the audience participants to make general statements concerning what they learned at the workshop and any lessons learned that could be applied to the ongoing review of the soil action levels.

Facilitator Laura Till explained that each of the expert panel members would have two minutes to present their issues, followed by representatives from the Working Group (DOE, Kaiser-Hill, EPA and CDPHE). The conversation would then turn to members of the audience. She advised that possible discussion points would include answering questions such as where do we go from here, what are the next steps, what would you like to see done next, what are you planning to do next, and what are you taking away from the workshop?

Expert panel members Art Rood, Kathleen Meyer, and Working Group member Jim Benetti were not able to remain for this final part of the workshop. John Till spoke for Art and Kathleen. Tim Rehder spoke for Jim.

Comments from the Expert Panel

Kathryn Higley: Dr. Higley reported that she found the workshop very enlightening. Her comments were made in three categories.

- Policy Issues: The soil action levels that are based on annual doses can be substantially different from those that are based on risk for the same conditions. How can this issue be resolved? Maybe the answer is to go back to a cumulative or integrated dose concept that better parallels lifetime risk.

- Technical Issues: Changing dose conversion factors make the soil levels moving targets. She asked whether as scientists they could make the dose conversion factors more robust and less susceptible to inevitable scientific tweaking. She offered that perhaps moving to probability distribution functions and then picking median or perhaps 95th percentile values for the dose conversion factors will generate numbers that are more stable and less likely to change as the science changes.

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- Communication Issues: We all need to keep the big picture in mind here. Scientists are always going to argue over the best way to do something, whether to model or to make calculations, or whatever. We need to remember that even huge changes in some of the parameters may not substantially change the outcome. The same thing can be said for new and improved models. It is good to look at a newer approach, but don't be surprised or disappointed if the results come back basically the same as your first calculation.

Charley Yu: Dr. Yu began by stating that he learned much at the workshop. He stressed that the numbers you put into the code are important because they are what determine your answer. Thus, you need to understand how the code uses parameters and you need to identify the sensitive parameters. If you have uncertainty for some parameters, you need to collect better data to feed into the code. Also, if you have distributions for parameters, it is better to input the distributions into the code and run the full Monte Carlo type of calculations to get the uncertainties, the 90th percentile or whatever. This method is better than choosing the 90th or 95th percentile value of the parameter and plugging a single value into the code. He closed by stating that everyone appears to be doing the best job they can, but even the best scientists in the world can make mistakes, especially when using computer codes. Although RESRAD is very user friendly, his experience shows that people make mistakes when they plug numbers into the code. He encouraged those who have not taken a RESRAD training course to do so.

John Till: Dr. Till first stated that he felt satisfied that his previous work is still being discussed, and for the respect that it has been shown. He reiterated that his team did not modify RESRAD. As others had analogized earlier, what they did was use "high test gas, even rocket fuel," to provide inputs to run the model. This is what happens when scientists are given mental freedom to think of how to do something the best they can. This is what science is all about. Even after what he has heard, he would not change anything that he did, but he would like to do some things more thoroughly. His team's work was to come up with a decision to protect human health to a given radiation dose. They did this to the best of their ability and given the data that they had to work with.

He has great respect for the RESRAD code, but he also has concern about its potential misuse in decisions of very high importance, which this decision is. As one looks at the model, it is a very good tool, but don't be mislead into thinking that it is very simple and that we know all the answers. This is a very important message for everyone to take home.

He stated that it is important to get site-specific data to run with the code. He gave an analogy that it is like buying a copy of legal software to write a will and then using the default values that come with the program. You wouldn't want to write a will unless it was custom driven. For his previous work, he couldn't obtain new data, he had to make do with what resources he had available.

In a message to the agencies, he stressed that stakeholder involvement is critical. Whatever decision is made about an RSAL is not just an agency decision. It is also a community decision. They should employ the best science.

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With respect to independence, he stated that in a decision as important as this, the RSAL should be developed by an entity totally independent of the agency that will employ the RSAL. EPA and CDPHE could do this, but he still prefers someone totally independent.

Regarding robustness of the final numbers, he stated that the only way to deal with uncertainty in dose and risk conversion factors is to employ some type of safety factor. One can do this at the decision level, or however one might choose, but this is the only way we have of dealing with these things.

Finally, he stated that he is concerned that three years after his work began, we still don't have a soil action level. If he were a local citizen, he would be concerned about the resources that have been put into other things, but not this decision.

Comments from the Working Group Members:

Steve Gunderson (CDPHE): Mr. Gunderson found the workshop to be very informative, but he is growing very tired of the RSAL process and is anxious to get things done. He stated that he must defer to the technical experts within the Working Group to determine what parameters to use, using the best scientific information and their best scientific judgment. They will be doing something similar to what Dr. Higley did at Johnston Atoll. They will be getting dose-based numbers and risk-based numbers that have a hundred-fold difference. On the risk side they will range from 10^{-4} to 10^{-6}. The Working Group will do the best they can to put numbers on the table, and then they will have a policy challenge to make the soil action level decisions, and ultimately the cleanup decisions. The full spreadsheet of numbers will be brought to the RFCA Focus Group to discuss.

John Rampe (DOE): Mr. Rampe learned a lot over the weekend. What struck him is that reasonable people can disagree on a number of things for a number of different reasons. Explanations include first that we are at the edge of our knowledge. For example, the fire scenario still needs much work. Second, people disagree because the RAC team and the current workgroup have been tasked somewhat differently, and as a result the numbers from the workgroup will disagree with RAC's numbers.

With respect to public process, since the first calculations were made, they are doing several important things very differently. Public input has led them to looking at things probabilistically. They are considering the fire scenario, even if it still needs work. Together we have made progress.

The next thing that will happen is that the workgroup will calculate numbers for a variety of different scenarios and risk levels. Once we have the numbers we will need to understand them, and then we can have a public policy discussion from there. His sense is that due to the workshop, even though people still disagree, we are in good shape to have a fruitful public policy discussion. He is optimistic that with respect to the soil action levels, people will ultimately find them reasonably protective.

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Bob Nininger (Kaiser-Hill): Dr. Nininger stated that work still needs to be done on technical issues, especially related to mass loading. He pointed out that even when they do come up with numbers, that doesn't mean work would stop on mass loading. He finds it frustrating to work in such a short period of time. He further stated that management decisions from the RSALs would be tempered by any new information that they might get. The RFCA process is a review process as well as a process of developing numbers. Numbers derived today may be modified in the future based on new information.

Tim Rehder (EPA): Mr. Rehder started out by stating that the more we learn about these questions, the more questions we have. It is harder to reach an endpoint. Jim Benetti asked him to report that with respect to mass loading, he will go back and talk with his colleagues in Las Vegas and with DOE representatives to determine if there might be information from other sites pertinent to this issue.

Mr. Rehder stated that Dr. Till had mentioned trying to do more monitoring around fires, not wind tunnel studies, but perhaps PM10 monitors. This is something the working group should look into, especially with the burn season coming up and the possibility of controlled fires in Boulder County in areas north of the site. It may make sense to coordinate with officials controlling these fires and put up some monitors to see what they can get out of that. Whatever comes out of these studies could be plugged into the mass loading question.

We don't have unlimited time to debate these issues. He is relying on Jim Benetti and Susan Griffin to come up with the Task 3 report that will have results expressed in dose and with a range of risks. He will send the report to EPA Headquarters' Office of Indoor Air and Radiation for technical review. Then we will need to make a management decision. They will use these calculations and consider other factors such as ALARA, protection of surface water quality, community acceptance and congressional support, and the whole idea of uncertainty that we have been talking about. Hopefully we can come up with an answer that is at least acceptable to most of us.

Comments from the Audience Participants:

Three members of the audience provided comments.

Commenter 1: We have come a long way since the early days at the site. An outstanding area of difficulty has been to come up with reliable data because the site didn't keep very good records. The work from 1996 did not meet with favor in the community because it was done without public knowledge or input. Things have improved since that time. This workshop reflects an attempt to allow the community to understand what is going on. The Working Group meetings are hard to attend. The RFCA Focus Group is a good process since anyone can attend, especially asset holders. Asset holders are distinctive from other stakeholders because they hold assets such as drinking water supplies in the area. With the Focus Group in place it is hoped that the process will result in the agencies paying attention to the stakeholders and asset holders.

Where do we go from here? We need another workshop that relates to health effects. Dose conversion factors keep moving around. Why do they move? What are the biasing inputs? Is it politics, industry contractor influence, budget constraints or what else? I would like to know how it is or why it is that the best scientific minds in the world keep moving these numbers around. The bottom line should be the health, safety and welfare of people living near these sites.

Commenter 2: The commenter agrees with the importance of this workshop. What struck the commenter is that in their comments regarding next steps, the agency representatives didn't mention the public, and this is the most important part of this process. The commenter doesn't want us to have to come back and do this again. We need the best science to do the job right now. It is important to have the public involved, which means no barriers to participation like meetings held in downtown Denver that are very difficult to get to.

We didn't need to start at ground zero. The regulators should have started with the RAC report and focused with the community on the areas of disagreement. In retrospect, the regulators have put a huge task on themselves. RAC's science was new and improved, showing that we shouldn't look at things like they always have been. We need people like John Till who will look outside the box. This is the challenge for us all.

Commenter 3: The commenter began by stating frustration with many years of Rocky Flats involvement. After five or six years, we still haven't gotten to first base on what is a safe level to leave the soil for permanent use by the public. There are no rules yet for what we should do with the contaminated soil. Frustration is palpable and time is running out. We are also threatened that the money supply is running out. We need to get off our backsides and do something.

Having no further individuals wishing to provide comments, Laura Till thanked everyone for attending, and the workshop adjourned.

This summary was prepared through a joint effort by Rocky Flats Citizens Advisory Board staff members Jerry Henderson, Ken Korkia, Noelle Stenger and Deb Thompson.

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ATTACHMENT I

Dr. Nininger provided the following examples of sensitive parameters for various pathways from most to least sensitive:

Soil Ingestion Pathway (Pu-239):

- Soil ingestion
- Indoor time fraction
- Thickness of contamination zone
- Depth of soil mixing layer
- Outdoor time fraction
- Area of contamination zone
- Density of contamination zone
- Precipitation
- Evapotranspiration Coefficient
- Irrigation

Plant Ingestion Pathway (Pu-239):

- Depth of roots
- Contaminated fraction, plant food
- Fruit, vegetable, and grain consumption
- Thickness of contaminated zone
- Leafy vegetable contamination
- Distribution coefficient contaminated zone
- Density of contaminated zone
- Precipitation
- Average annual wind speed
- Evapotranspiration coefficient

External Pathway (Pu-239):

- External gamma shielding factor
- Indoor time fraction
- Density of contaminated zone
- Thickness of contamination zone
- Outdoor time fraction
- Area of contaminated zone
- External gamma
- Inhalation
- Plant ingestion
- Meat ingestion

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Inhalation Pathway (Pu-239):

- Average annual wind speed
- Inhalation rate
- Mass loading for inhalation
- Indoor dust inhalation shielding factor
- Indoor time fraction
- Depth of soil mixing layer
- Outdoor time fraction
- Area of contamination zone
- Density of contamination zone

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Stakeholder Workshop – Outcomes and Issues

Suggestions from the Panel of Experts

On Mass Loading:

- **John Till: It seems prudent to assume the probability of fire is 1 for compliance with an annual dose limit.**
- **John Till: It might be informative to perform an investigation similar to the wind tunnel studies on a larger scale in the natural environment.**
- **Kathryn Higley: The wind tunnel simulates resuspension due to horizontal movement, but the question of vertical-pounding, or turbulence, needs to be explored.**
- **Art Rood: Another source of information might be the dose reconstruction studies. Historical monitoring data is available for a time when the 903 Pad Area was burned.**

On How to Account for Changes in Dose Conversion Factors:

- **Kathryn Higley: Viewing dose conversion factors as probability distributions might result in greater stability over time.**
- **John Till: One solution might be to select the most conservative factor that has been proposed for each pathway. That could mean using an inhalation factor from ICRP 26 and a soil ingestion factor from ICRP 67, for instance.**

On Expertise in Using the Computer Model:

- **Charley Yu: It is imperative to understand how the model uses parameters in order run the model correctly. Even the best scientists can easily make mistakes.**

- **John Till: He has great concerns about the potential misuse of RESRAD.**

On Data Collection:

- **John Till: He stresses the importance of gathering site-specific data.**
- **Charley Yu: If you have uncertainty for some of the parameters, you need to collect better data to input to the code.**

On the Groundwater Pathway:

- **John Till: RESRAD cannot handle groundwater the way it should be handled. This issue needs to be given serious consideration.**

RFCA Stakeholder Focus Group
Attachment D

Title:	RSALs Working Group Notes for September 13, 2001
Date:	September 20, 2001
Phone Number:	(303) 428-5670
Email Address:	cbennett@alphatrac.com

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NOTES FROM RSALs WORKING GROUP MEETING ON 9/13/01

ITEMS COVERED ON 9/13:

1. Task 3 report status.
2. Action items.

ACTIONS

Action Item	Who	When	Notes
Revise Resident Rancher Scenario description, send to Tricia Powell/group.	Jim Benetti	9/19/01	
Provide write-up on slope factors to Tricia Powell/group.	Richard Graham	9/21/01	
Re-do risk calculations for open space and office worker scenarios using 95th percentile for mass loading.	Susan Griffin/Phil Goodrum	9/20/01	
Send out risk spreadsheet with justifications.	Susan Griffin/Phil Goodrum	9/14/01	
Prepare list of terms from draft Task 3 report that should be in the glossary.	Tricia Powell	after Task 3 report is drafted	
Provide all write-ups to Tricia Powell!!	Everyone	ASAP	
Run RESRAD for resident rancher scenario using only RAC numbers, for comparison purposes.	Jim Benetti	9/20/01	
Revise remaining Conceptual Site Model flow charts.	Carl Spreng & Mark Aguilar	9/20/01	

DECISIONS

1. Use 95th percentile mass loading value for all deterministic calculations.
2. Put date on all draft documents that are being prepared for the Task 3 report.
3. For the Task 3 report, round all RSAL numbers to the nearest whole number.

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NEXT MEETING: THURSDAY, 9/20/01, 8:30 a.m., at ROCKY FLATS B060

Agenda Items:

1. Discuss status of Task 3 report.
2. Discuss resident rancher RESRAD runs.
3. Discuss plans/schedule for uranium calculations.
4. Go through action item table.

RFCA Stakeholder Focus Group
Attachment E

Title:	Latest version of the preliminary surface RSAL matrix
Date:	September 20, 2001
From:	RSALs Working Group
Phone Number:	(303) 428-5670
Email Address:	cbennett@alphatrac.com

Attached is the latest version of the matrix, which includes Risk calculations for the Open Space and Office Worker scenarios. You will also notice slight changes in the sum of ratios numbers for the other scenarios. This is due to calculating the sum of ratios using a slightly different Am:Pu activity ratio of 0.1527. This ratio was derived during the characterization work performed on the 903 Pad and Lip Area a couple of years ago. The numbers that were provided to the Focus Group in early August were based on an activity ratio of 0.1364. Using the updated activity ratio results in slightly lower sum of ratios calculations for plutonium.

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September 18, 2001

PRELIMINARY Dose & Risk Calculations for Plutonium in Surface Soil – Adjusted by Sum-of-Ratios Method* (pCi/g)

Land Use Scenario	Risk Levels			25-mrem annual dose
	10^{-4}	10^{-5}	10^{-6}	
Wildlife refuge worker [a]	498	50	5	862
Rural Resident – adult [a]	189	19	2	209
Rural Resident– child [a]				244
Open Space User – adult [b]	3490	349	35	8459
Open Space User – child [b]				4842
Office Worker [b]	596	60	6	2289

* This example accounts for additional activity from Am using a sum-of-ratios method, and assumes that the Am:Pu activity ratio equals 0.1527 and that only Am and Pu are present.
[a] Probabilistic (95th percentile)
[b] Deterministic

September 18, 2001

Dose Calculations for Plutonium in Surface Soil (pCi/g)

Land Use Scenario	15-mrem dose	25-mrem dose
RAC Resident Rancher – adult		
RAC Resident Rancher – child		

Dose Calculations for Plutonium in Surface Soil - Adjusted by Sum-of-Ratios Method (pCi/g)

Land Use Scenario	15-mrem dose	25-mrem dose
RAC Resident Rancher – adult		
RAC Resident Rancher – child		